THE

MASSACHUSETTS INSTITUTE OF TECHNOLOGY,

BOYLSTON STREET, BOSTON, MASS.

FRANCIS A. WALKER, PRESIDENT.

THE SCHOOL OF INDUSTRIAL SCIENCE aims to give thorough instruction in CIVIL, MECHANICAL, CHEMICAL, MINING, ELECTRICAL, and SANITARY ENGINEERING, in CHEMISTRY, ARCHITECTURE, PHYSICS, BIOLOGY, and GEOLOGY. It offers also a course in BIOLOGY, preparatory to the study of MEDICINE, and a GENERAL COURSE based upon scientific study and experiment, but admitting of more instruction in language, literature, and political science than is possible in the other courses.

To be admitted to the School, the applicant must have attained the age of seventeen years, and must pass examinations in arithmetic, algebra, plane geometry, history of the United States (or ancient history), English, French (or German), and geography. A definite division of these examinations between two successive years is allowed. In general, it may be said that a faithful student who has passed creditably through a good High School, having one year's study of French (or German), ought to pass the Institute examinations without much difficulty.

Examinations will be held on June 25th and 26th, 1891, in Boston, New York, Philadelphia, Chicago, Washington, San Francisco, St. Paul, Pittsburgh, St. Louis, Cincinnati, Montreal, and Toronto; and on September 22d and 23d, in Boston only.

Instruction is given by means of lectures and recitations, supplemented by appropriate work in the laboratory, drawing-room, or field. To this end, extensive laboratories of chemistry, physics, biology, mining, mechanical engineering, applied mechanics, and the mechanic arts have been thoroughly equipped, and unusual opportunities for field-work and for the examination of existing structures and industries have been secured. It is sought to give, so far as is practicable, personal instruction to small sections, rather than lectures to large bodies of students.

The regular courses are of four years' duration, and lead to the degree of Bachelor of Science. Shorter special courses are offered to those properly prepared, and advanced degrees of Master or Doctor of Science and of Doctor of Philosophy are given for study subsequent to graduation.

The tuition fee, including everything except breakage in the chemical laboratory, is $200 a year. In addition, $25 or $30 per year are required for books and drawing materials.

For Catalogues and information, address

J. B. HENCK, JR., *Secretary*.

THE ATLANTIC WORKS,

INCORPORATED 1853.

60 TO 76 BORDER STREET, EAST BOSTON, MASS.

BUILDERS OF

STEAMSHIPS, TOW BOATS, & STEAM YACHTS,

Marine Engines, Boilers, Tanks, and General Machinery.

REPAIRING OF EVERY DESCRIPTION.

KIDDER, PEABODY, & CO.,

Bankers,

NO. 113 DEVONSHIRE STREET, BOSTON,

NEW YORK OFFICE, 1 NASSAU STREET,

Issue MERCANTILE and TRAVELLER'S CREDITS,

available in all parts of the world, through

MESSRS. BARING BROTHERS & CO.,

LONDON,

and their correspondents. Buy and sell Foreign Exchanges and Telegraphic Transfers on Europe, California, and the British Provinces.

STOCK AND BOND ORDERS

EXECUTED IN BOSTON, NEW YORK, AND PHILADELPHIA.

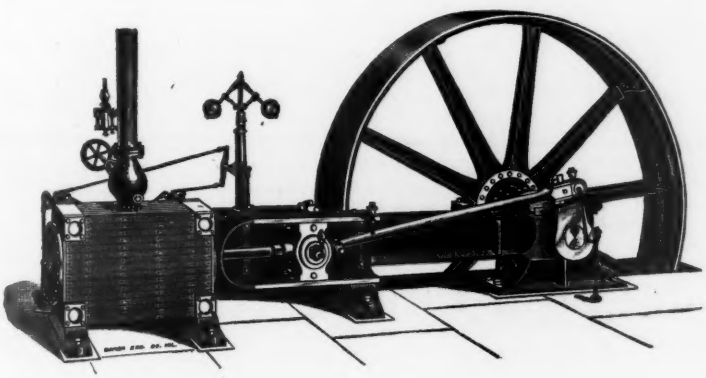
THE EDWARD P. ALLIS COMPANY,

MILWAUKEE, WISCONSIN.

Reynolds Corliss Engines,

EITHER CONDENSING, COMPOUND, OR TRIPLE EXPANSION,

For Any Kind of Service. Highest Efficiency Guaranteed.



HIGH DUTY PUMPING ENGINES.

HEAVY HOISTING ENGINES.

BLOWING ENGINES.

AIR COMPRESSORS.

ROLLING MILL ENGINES.

VERTICAL AND HORIZONTAL BOILERS.

CATALOGUES FURNISHED ON APPLICATION.

PITTSBURGH TESTING LABORATORY.

HUNT & CLAPP,

95 FIFTH AVENUE, PITTSBURGH, PENN.

Metallurgical and Inspecting Engineers and Chemists.

SPECIALTIES.—Inspection of rails and of material for bridges and other structures, reports and advice upon metallurgical operations, chemical analyses of all kinds, physical tests of iron and steel, including tensile, transverse, and compression tests.

Agents of Eimer & Amend, New York, for Chemical and Metallurgical Supplies.

Agency for Tinius Olsen & Co.'s Testing Machines.

Agents for Carl Spaeter's Magnesite Bricks and other Magnesite Refractories, especially designed for basic open-hearth steel furnaces.

COCHRANE CHEMICAL CO.

55 KILBY STREET, BOSTON,

MANUFACTURERS OF

OIL VITRIOL,	SULPHATE OF AMMONIA,	EXTRACT OF INDIGO,
MURIATIC ACID,	AQUA AMMONIA,	GLAUBER'S SALT,
NITRIC ACIDS,	SULPHATE OF SODA,	ACETIC ACID,
MURIATES OF TIN,	STANNATE OF SODA,	TIN CRYSTALS,

MIXED ACID FOR NITRO GLYCERINE, CELLULOID, &c.,

And various other Chemicals.

Business Founded 1849. Works at EVERETT, MALDEN and EAST CAMBRIDGE.

BOSTON WOVEN HOSE CO.,

MANUFACTURERS OF

RUBBER BELTING AND HOSE.

We make a specialty of Mould Work, and take extra pains with Experimental Work.

OFFICES:—226 Devonshire Street, Boston; 222 Lake Street, Chicago; 8 Bush Street, San Francisco.

NO MORE DUTY ON BOOKS IN FOREIGN LANGUAGES.

French, German, English (etc.) Books and Periodicals, supplied at special low rates to former and present members of the Institute of Technology.

CARL SCHOENHOF,

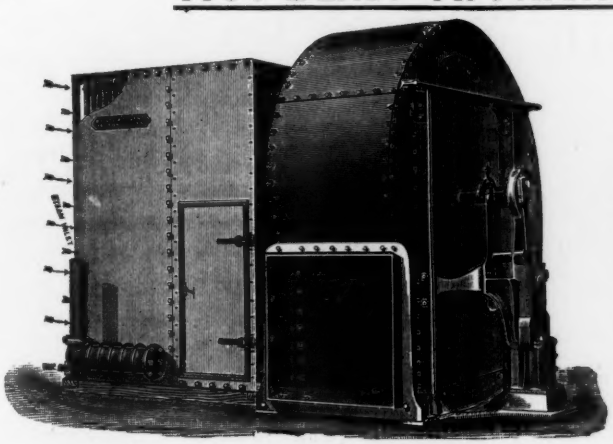
IMPORTER AND FOREIGN BOOKSELLER,

144 TREMONT STREET, BOSTON.

SEND FOR CATALOGUES.

THE STURTEVANT STEAM HOT-BLAST APPARATUS.

FOR HEATING and VENTILATING



BUILDINGS OF ALL KINDS.

OFFICE AND WORKS:

THE B. F. STURTEVANT CO. JAMAICA PLAIN, BOSTON, MASS.

—COAL—

OF THE BEST QUALITIES

For Family Use and for Steam Users.

WOOD PREPARED FOR KINDLING AND FOR OPEN FIRES.

LACKAWANNA, CUMBERLAND,
OLD COMPANY'S LEHIGH, NEW RIVER,
ENGLISH CANNEL, LEHIGH,
LYKENS VALLEY FRANKLIN.

We have supplied the Institute of Technology for five years.

GEO. M. WINSLOW & COMPANY,

139 Cross Street. 228 and 280 Causeway Street,

BOSTON.

THE · THOMSON-HOUSTON

ELECTRIC · COMPANY,

MANUFACTURER · OF

ELECTRICAL · APPARATUS · FOR · ELECTRIC · ARC LIGHTING · INCANDESCENT · LIGHTING · BY DIRECT · AND · ALTERNATING · CURRENTS. * *
IMPROVED · SYSTEMS · OF · ELECTRIC · STREET RAILWAYS. * *
ELECTRIC · TRAMWAYS · FOR · MILLS · AND · MINES.
ELECTRIC · MOTORS. * *

THE · THOMSON-HOUSTON · ELECTRIC · CO..

620 · ATLANTIC · AVE., · BOSTON, · MASS.

148 · MICHIGAN · AVE., CHICAGO, · ILL.

WALL · & · LOYD · STS., ATLANTA, · GA.

403 · SIBLEY · STREET, · ST. · PAUL, · MINN.

TECHNOLOGY QUARTERLY.

VOL. IV. APRIL, 1891. NO. 1.

THE PROPERTIES, USES, AND PROCESSES OF PRODUCTION OF ALUMINUM.[1]

BY ALFRED E. HUNT, S.B., PRESIDENT OF THE PITTSBURGH REDUCTION COMPANY.

THE metal aluminum has certainly not been "damned by faint praise." On the contrary, from my experience as the president of an aluminum manufacturing company which has been endeavoring for the past two years and over to sell the commercially pure metal in the markets, and to introduce it into the arts and manufactures of the country, I have to state to you as my conviction that one of the two chief difficulties encountered, and which today retards and restricts the wider use of the metal, is the extravagant, erroneous, and in many cases mischievously misleading, statements which have been made as to the properties of the metal, which have received wide circulation, not only through the daily newspapers, but, I am sorry to add, through many technical and scientific journals as well. The other difficulty is the almost equally widespread, and, so far, equally extravagant and misleading, series of claims made by the inventors of processes for the manufacture of aluminum at remarkably low prices.

I shall endeavor in this lecture to correct some of these fallacies as to the properties of the metal, and also, in describing the minerals in which the metal occurs and the methods of reduction which have been practiced, to explain the principal difficulties which have thus far been encountered. I shall also venture a prophecy as to the success of cheaper methods of manufacture of aluminum in the future.

[1] A lecture before the Society of Arts, Massachusetts Institute of Technology, February 12, 1891.

PURE AND IMPURE ALUMINUM.

Some of the erroneous statements regarding aluminum have had their origin in the fact that commercial aluminum is never chemically pure, and that until within the past eight years nearly all the aluminum of which the properties had been described had at least 4% — in many cases 6% or 8% — of impurities. These materially altered the characteristics from those of the purer metal, with not over 2% or at most 3% of impurities, which is ordinarily sold in the markets today.

The impurities almost always found in aluminum are silicon and iron. These two impurities are almost the only ones found in the electrolytically deposited metal, considerable amounts of any others being accidental and due to carelessness in manufacture. In fact, I hope to be able in the near future to say that the impurity consists of the single one, silicon, as we have already made many hundred pounds of aluminum, with only a trace of iron present, and tons of metal with less than $\frac{1}{10}$ of 1% of iron.

The silicon present in aluminum exists in two forms, one seemingly combined with the aluminum, as combined carbon exists in white pig iron, and the other in an allotropic graphitoidal modification. These two forms of silicon seem to exert somewhat different effects by their presence in the aluminum; the combined form of the element rendering the metal much harder than the graphitoidal variety. The combined silicon ordinarily preponderates, being from 55% to 80% of the total silicon in the average metal of between 98% and 99% purity made by the Pittsburgh Reduction Company.

For many purposes, the purest aluminum cannot be so advantageously used as that containing 3% or even 4% of impurity, as the pure metal is very soft and not so strong as the less pure. It is only where extreme malleability, ductility, sonorousness, or non-corrodibility is required that the purest metal should be chosen. We shall probably find that for most purposes a small percentage of other elements than silicon and iron are advantageously added in producing hardness, rigidity, and strength — constituents that will not detract from the non-corrodibility of the metal as much as do these natural impurities that come from the ore and apparatus — additions that will give the aluminum a better color and greater strength and hardness, with proportionately less sacrifice of malleability, ductility, etc.

COLOR OF ALUMINUM.

Pure aluminum is white, with a decided bluish tint. This becomes much more marked upon exposure, when a thin film of white oxide on its surface prevents further tarnishing from the air, but seems to give, by contrast to the metal as a background, an enhanced bluish tint. I am sorry to hear my good wife report this color as giving a decidedly pewtery appearance to the spoons and forks which we have had in almost constant daily use, for comparison with silver, during the past year and a half. The oxide which gives this decided blue tint may be removed by immersion in a dilute solution of hydrofluoric acid, and then rubbing with chamois skin saturated with petroleum.

No one should expect the color of silver in aluminum — especially of silver of the markets, which is given a decided yellow tinge with copper; for the natural color of aluminum is different, and the addition of copper, although making the metal a yellower white, does not entirely change its natural bluish-white tint. The addition of small percentages of silver, chromium, manganese, wolfram, or titanium, undoubtedly improves the color of aluminum, making it nearer to that of silver.

ACTION OF HEAT ON ALUMINUM.

Aluminum melts at about 1,300° F., but becomes pasty at a temperature of about 1,000° F., and indeed loses its tensile strength and very much of its rigidity at a temperature of 400° to 500° F., although this loss of strength is only while the metal is kept at the high temperature. It serves as an annealing operation, and reduces permanently only the higher tensile strength produced by cold rolling or otherwise cold working the metal. Aluminum does not volatilize at any temperature ordinarily produced by the combustion of carbon, even though the high temperature be kept up for a considerable number of hours. It, however, absorbs a very large amount of occluded gases under such treatment. In the high temperature of the electric furnace, it is claimed that there is considerable volatilization of aluminum, and that small buttons of the metal have been found in and on the linings of the furnace. The Cowles people, however, have never been enabled to collect and commercially produce pure aluminum by their electric furnace, for the reason that the metal rapidly oxidizes into alumina.

It has only been by protecting the reduced metal with an alloy of either iron or copper that they have succeeded at all in retaining the reduced aluminum.

Under heat, the coefficient of linear expansion of $\frac{8}{8}$ in. round aluminum rods of 98.50% purity is .0000206 per degree centigrade between the freezing and boiling points of water; that of iron being .0000122, tin .0000217, copper .000017182. Multiplying this factor by $\frac{5}{9}$ to reduce it to the Fahrenheit scale, we have .0000115, or an expansion of .00115 ft. on 100 ft. of aluminum raised 1° F. from 32°. It is probable that the coefficient of expansion of alloys of aluminum is very close to that of tin.

The specific heat of aluminum is 0.2143, water being taken as 1. The metal follows the general rule of metals, its specific heat being inversely as the atomic weight.

By the method of Weidermann and Franz, taking silver as 100 and copper as 73.6, unannealed aluminum of 98.50% purity has a coefficient of thermal conductivity of 37.96; and the same wire annealed, 38.87. In the same scale, tin has a heat conductivity of only 14.50, iron 11.90, steel 11.60, and lead 8.50. From this it is evident that, next to silver, copper, and gold, soft annealed aluminum is the best conductor of heat.

ELECTRICAL PROPERTIES OF ALUMINUM.

It also stands next to silver, copper, and gold, as a conductor of electricity. One yard of annealed aluminum wire of 98.50% purity, .0325 inch in diameter, at 14° C. has .05484 of an ohm resistance, a yard of pure copper wire of same section having a resistance of .0315 of an ohm. The electrical conductivity of silver being taken at 100, and copper at 90, pure annealed aluminum has an electrical conductivity of about 50. These facts, taken into consideration with the lightness of the metal as compared with silver, gold, and copper, are already leading to a quite extensive use of aluminum in electrical apparatus.

Pure aluminum, and indeed the electrolytically made commercial aluminum, with less than $\frac{1}{5}$ of 1% iron, regularly put upon the market today, exhibits no appreciable polarity. Such metal has many advantages for compass boxes, or for cases for electrical apparatus where non-magnetic properties are desired.

MECHANICAL PROPERTIES OF ALUMINUM.

The fracture of aluminum shows ordinarily hexagonal crystals, although the pure metal is very tough, and in breaking, by bending backward and forward, often appears distinctly fibrous in fracture. The lack of rigidity and hardness which the metal exhibits is a serious obstacle to its adaptability for many purposes, although both stiffness and hardness are very much increased by the addition of a few per cent of impurities or alloy, and are especially improved by cold-hammering, cold-rolling, drop-forging, or the like. For castings for surveying instruments, pure aluminum would be especially adapted were it not for its softness and lack of rigidity. It can be safely stated as a general rule that the purer the aluminum, the softer and less rigid it is.

Pure aluminum is, when properly treated, a very malleable and ductile metal. It can readily be rolled into sheets five ten thousandths of an inch thick, or be beaten into leaf nearly as thin as gold leaf, or be drawn into the finest of wire. Pure aluminum stands third in the order of malleability, being exceeded only by gold and silver; and in the order of ductility, seventh, being exceeded by gold, silver, platinum, iron, softest steel, and copper. Both malleability and ductility are greatly impaired by the presence of the two common impurities, silicon and iron.

Aluminum can be rolled or hammered cold, but the metal is most malleable at between 200° and 300° F., and should be heated to this point for rolling or breaking down from the ingot to the best advantage, and even then considerable power is required, fully as much as for hot-rolling of hard steel of similar section, although not nearly as much draft can be placed upon the rolls as in hot-rolling hard steel. Like silver and gold, aluminum stiffens up remarkably by working it, increasing a great deal its hardness and its tensile strength, and decreasing its malleability and ductility; it requires to be frequently annealed. As compared with cold-rolling soft steel, it has been found practicable to give aluminum about the same reduction in each pass as the steel; the aluminum requiring on the average five annealings where the steel requires but three.

By hardening the metal by rolling, forging, drop-forging, stamping, drawing, etc., it may be turned out very rigid, and will then answer

excellently for purposes where the annealed metal would be entirely too soft, too weak, or lacking in rigidity or elasticity. Especially is this true of aluminum alloyed with a few per cent of titanium, copper, iron, silicon, or the like. The alloys do not show their increased hardness to anything like their maximum extent in castings, and, I am sorry to say, not at all in proportion to the increased brittleness. But when these castings are drop-forged, rolled, hammered, or drawn down, with only sufficiently frequent annealings to prevent the metal from cracking, the increased hardness shows up in a remarkable degree. These properties have already become not only the subject of a considerable number of letters patent, but also of established uses in the arts, and will, in future, add enormously to the applicability of the metal.

ANNEALING ALUMINUM.

To anneal aluminum, a low and even temperature should be maintained in the muffle—just such a temperature as will show an even, red heat in a piece of iron or steel placed in the muffle, when viewed at twilight or on a dark day. The aluminum itself, however, should not appear at all red at this temperature. A ready test of this temperature is that the metal has been heated enough to char the end of a pine stick, which will leave a black mark on the plate as it is drawn across it. When the metal has acquired this temperature, it should be taken from the furnace and allowed to cool gradually. Very thin sections may be annealed by placing into boiling water and either allowing to cool with the water or taking out to cool gradually. Of course it is possible to anneal to any degree by lowering the temperature to which the metal is heated below that specified by means of suitable appliances.

WELDING AND SOLDERING ALUMINUM.

Aluminum can be easily and readily welded by the apparatus of the Thomson Electric Welding Company.

Until very lately the lack of methods for successfully soldering and hardening aluminum were two of the greatest drawbacks to its introduction for many purposes. I am glad to be able to say to you, however, that both of these difficulties, I believe, have lately been successfully evercome. I have already outlined to you the method of alloying pure aluminum with a few per cent of hardening-metal, and cold-rolling

or otherwise working, as being ways out of the difficulty of its softness. The exhibitions of soldered metal will show you that aluminum can now be successfully soldered. These results were obtained by the use of the blow-pipe and with ordinary hard or soft solder, or with pure zinc, or with an alloy of zinc and aluminum, as the soldering metal. The novelty, which has just been covered by letters patent in one successful case, is in the soldering salt, which allows the solder to flow freely on the surfaces to be united.

CASTING ALUMINUM.

Sound castings of aluminum can be readily made in dry sand molds. The aluminum should not be heated very much beyond the melting point; otherwise it seems to absorb gases, which remain in the metal, preventing sound castings. In small quantities the metal can be best melted in plumbago crucibles; but in large quantities it can be more economically melted in a reverberatory furnace with alumina or magnesia brick sides and alumina bottom. The furnace should have a tap-hole for drawing off the liquid metal into carbon-lined ladles. In no case need the metal be covered with a flux to assist in the fusion or to form a covering of slag. In fact, owing to the metal's lightness, the presence of any flux will tend to unsoundness, due to particles of it becoming entangled in the castings, while impurities may perhaps be added to the metal by the action of the flux on the lining of the melting vessel. The molten metal flows readily, and not much larger gates are needed than for brass. The shrinkage of $\frac{15}{64}$ in. per ft., which aluminum has, is considerably more than that of brass, which is about $\frac{3}{32}$ in. per ft. The shrinkage can be reckoned ordinarily as about 2.26% of the length of the mold. Wooden patterns made for brass, to give equivalent castings of aluminum, should be given three or four thick coatings of shellac.

RESISTANCE OF ALUMINUM TO CORROSION.

As to the corrodibility of aluminum, a great deal has been printed that is not correct. In the first place, aluminum is acted upon by the atmosphere, especially by moist atmosphere, and more especially still by moist salt atmosphere. The metal becomes covered by a very thin, almost imponderable, coating of oxide on the surface exposed to the atmosphere, which seems to protect it from further oxidation. This

coating is so thin as often to hardly interfere with any polish, and it does not materially change the weight of the metal. It does, however, increase the bluish tint of the metal, as before explained, and gives it a leadish color. As compared with most metals, pure aluminum, under ordinary circumstances, withstands the action of wind and weather exceedingly well; and many uses to which the metal is now being successfully applied are based upon this fact. The presence of silicon in aluminum materially detracts from its power to withstand corrosion due to atmospheric influences. Metal with 4% or 5% of silicon very soon collects a thick coating of oxide upon it, if severely exposed. The fact that pure aluminum is not acted upon by boiling water or by steam has led to its use as a packing or gasket in steam connections, where lead and similar metals have been rapidly cut out (especially where the water contained notable amounts of sulphur acids), as in parts of steam and water pumps and difficult steam joints. The New York Steam Company have found it a very satisfactory way of packing their leaky steam joints to put in first a layer of aluminum wire, without attempting to calk it much, adding another ring of the softer, but more easily corroded, lead on the outside, which can be calked into place, making the joint steam-tight.

Aluminum containing sodium is rapidly acted upon by hot water, the sodium being eaten out, leaving the aluminum spongy and porous. Aluminum is unaffected by either concentrated sulphuric or nitric acids. Unfortunately, however, these commercial acids almost always contain some little hydrochloric acid, which rapidly corrodes the aluminum, the chloride of aluminum first formed being changed into sulphate or nitrate, the free hydrochloric again acting more violently as it attacks the metal in a nascent state.

Aluminum is not acted upon by carbonic acid, or carbonic oxide gases, nor by sulphuretted hydrogen except at a red heat; but it is a peculiarity of the metal in a melted condition to absorb large quantities of these gases, quite a portion of which is again excluded as the metal cools. But enough is left in the case of the sulphide to emit strong odors of the sulphuretted hydrogen which has been occluded and imprisoned in the metal in cooling. This fact is a strong obstacle to a sulphide method of reduction of the metal, where the sulphuretted hydrogen evolved would strongly impregnate the metal for a long time, even after several meltings.

ALUMINUM FOR CULINARY AND SURGICAL PURPOSES.

Pure aluminum has neither taste nor odor, nor is it corroded by any substances ordinarily used in culinary operations, and it seems, therefore, especially adapted for cooking utensils. For spoons, forks, and large dishes, the metal also is useful, although its color can be improved, and the metal made more rigid, by a slight addition of copper.

Aluminum is less acted upon than is tin or copper or silver by salt water, and even by such solutions in vinegar as the metal is liable to be subjected to in ordinary culinary vessels. The salts of tin or copper thus dissolved are very poisonous; but not only are the aluminum salts that are formed less in amount, but the acetate of aluminum formed resolves itself on boiling into either an insoluble sub-acetate or into pure alumina, neither salt having either taste or injurious toxic action. For these reasons, quite surely aluminum will have a large future for cooking utensils. A cooking skillet of aluminum has been in service for a year in my own household.

Aluminum is found to withstand the action of organic secretions better even than silver, and for many forms of surgical instruments, tracheometer tubes, suture wires, and the like, and for forms for holding false teeth, the metal is already receiving very wide use. Many surgeons are having their instrument cases made of aluminum, it having the advantage that they can safely be washed clean with antiseptic solutions. It may be well for me to say here, however, that perspiration in handling polished aluminum does tarnish the metal, and that aluminum, like other metals, cannot retain a high polish with frequent handling. The natural acid solvent for aluminum is hydrochloric acid. Solutions of the caustic alkalies, chlorine, bromine, iodine, and fluorine rapidly corrode aluminum. Ammonia gas has very little action on the metal, except to turn it a gray color. Strong aqua-ammonia has a slight solvent action upon it.

OTHER PHYSICAL PROPERTIES OF THE METAL.

The specific gravity of aluminum, of course, is one of its most striking properties — a property on which many brilliant "castles in the air" have been built. It runs from 2.56 to 2.70; structural steel is 2.95 times as heavy, copper 3.60 times, ordinary high brass 3.45

times, nickel 3.50 times, silver 4 times, lead 4.80 times, gold 7.70 times, and platinum 8.60 times as heavy. Many uses have been suggested for the metal due to its lightness; one is for the entire framework of air ships. Now as there are many strong woods which have a specific gravity below 1, and which are, therefore, about one third the weight of aluminum, and as woods can be selected that will by no means require three times the section of aluminum to give equal strength for frames, I do not quite understand where the applicability of aluminum for this purpose comes in. Of course, in many cases a much thinner sheet or smaller section of aluminum could be used than of wood; but for purposes where rigidity as well as lightness is required, the parts of air ships could be made much better of wood than of aluminum. I will confess that as aluminum is a favorite metal of mine, I am loth to see it subjected to the rude falls to which, I fear, it will be endangered if attempts are made to build air ships of it.

Pure aluminum is very sonorous, and varying qualities of sound are given by its different alloys. Unfortunately, just the right shape for an aluminum bell has not yet been discovered. The ordinary forms give out anything but an agreeable sound.

THE STRENGTH OF ALUMINUM.

Cast aluminum has about the ultimate strength of cast iron in tension, but under compression it is comparatively weak.

The following table gives the average results of many tests of aluminum, having about the following composition: Aluminum, 97% to 99%; silicon graphitic, 0.10% to 1%; silicon, combined, 0.90% to 2.80%; iron, 0.04% to 0.20%.

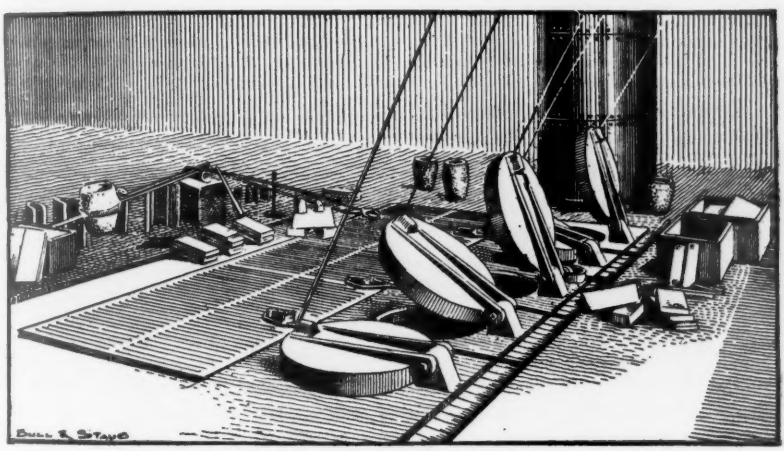
Tension tests.	Castings.	Sheet.	Wire.	Bars.
Elastic limit per sq. in., lbs. . .	6,500	12,000	16,000 to 30,000	14,000
Ultimate strength per sq. in., lbs.	15,000	24,000	30,000 to 60,000	28,000
Reduction of area	15%	35%	60%	40%

Compression tests (in cyclinders with length twice the diameter):

Elastic limit per sq. in.	3,500 lbs.
Ultimate strength per sq. in.	13,000 lbs.

The modulus of elasticity of cast aluminum is about eleven million; cold drawn aluminum wire, about nineteen million; aluminum sheets, about thirteen million.

Under transverse test pure aluminum is not a very rigid metal. An inch square bar of good cast iron, supported on knife edges 4 ft. 6 ins. apart and loaded in center, will readily stand 500 lbs. without a deflection of over 2 ins. A similar bar of aluminum would deflect over 2 ins. with a weight of 250 lbs., although the aluminum bar would bend nearly double before breaking, while the cast-iron bar will ordinarily break before the deflection has gone very much beyond 2 ins. Aluminum to withstand strains, and especially to have good elasticity, should be alloyed with a few per cent of impurities and cold-rolled, or otherwise worked cold. In this way it can be made to be nearly as strong and elastic as mild steel, section for section, and weight for weight will be much more rigid.



MELTING HOLES — PITTSBURGH REDUCTION COMPANY'S PROCESS.

ALLOYS OF ALUMINUM AND COPPER.

Aluminum and copper form two series of valuable alloys; the aluminum bronzes, ranging from 2% to 12% aluminum with copper, and the copper hardened aluminum series, with from 2% to perhaps 15% of copper with the aluminum. The aluminum bronze series are already beginning to assume an important position in the arts, and I believe will very largely replace brass and other bronzes, and for some purposes

take the place of steel. By adding 8% to 12% of aluminum to copper, we obtain one of the densest, finest grained, and strongest metals known — a metal having a remarkably good ductility as compared with its tensile strength. A 10% bronze can readily and uniformly be made in forged bars, with 100,000 lbs. per square inch tensile strength, with 60,000 lbs. elastic limit per square inch, and with at least 10% elongation in 8 ins., and aluminum bronzes can be made to meet a specification of even 130,000 lbs. per square inch and 5% elongation in 8 ins. Such bronzes have a specific gravity of about 7.50, and are of a light yellow color. The 5% to 7% aluminum bronzes have from 8.30 to 8 specific gravity, and a handsome yellow color. They readily give 70,000 to 80,000 lbs. per square inch tensile strength, with over 30% elongation in 8 ins. and with an elastic limit of over 40,000 lbs. per square inch. It will probably be alloys of the latter character that will be most used, especially for marine work. The fact that 5% to 7% bronzes can be rolled or hammered at a red heat, proper precautions which can readily be secured being taken, will add greatly to their use. Metal of this character can be worked in almost every way that steel can, having for its advantage greater combined strength and ductility, and much greater power to withstand corrosion. By far the best results have been obtained by using the purest aluminum and purest copper. The presence of silicon in aluminum alloys makes a harder bronze, but one of much less comparative ductility and malleability. The presence of iron weakens and very seriously interferes with the value of bronze. Tin also is disadvantageous. The presence of zinc in the aluminum bronze is not so deleterious; in fact, it makes the best aluminum brasses much better than those having tin in them.

The Cowles and Heroult people, who by their methods manufacture aluminum bronze by direct reduction, have claimed that the bronze directly reduced was more homogeneous and better than that made by melting together copper and pure aluminum. Careful experiments made in this matter, however, have failed to show this claim to be true. From my experience, I entirely agree with Professor Richards, who, in his excellent work, says: "Two specimens containing nothing but aluminum and copper in like proportions will be identical, no matter how they are produced." As it is far easier, and at present cheaper, to produce a bronze with less iron and silicon by using pure aluminum of less than 2% of these impurities, which with

pure copper will give less than $\frac{1}{5}$ of 1% impurity in the bronze, the advantage is certainly on the side of the use of pure aluminum, melting it with pure copper, so far as quality is concerned.

The aluminum in bronzes lowers the melting point of the copper at least 100° or 200°. The melting point of 10% aluminum bronze is somewhere in the neighborhood of 1,700° F.

WORKING ALUMINUM BRONZE.

Aluminum bronze is among the hardest of the bronzes, and hardens upon cold-working considerably. This hardness, however, can readily be lowered by annealing at a red heat and plunging into cold water. Aluminum bronze can readily be worked in a lathe, and the chips cut clean, smooth, and long, and do not clog the tool. Aluminum bronze is a remarkably rigid metal under transverse strain, being much more rigid than ordinary brass, or even gun bronze. Under compression its strength, although rather low in elastic limit compared to its ultimate compressive strength, is still much higher than that of any of the other bronzes, and there is a long period of gradual compression before finally giving way, making it peculiarly a safe metal under compression.

Aluminum bronze has excellent anti-friction qualities, owing to its fine grain texture and peculiar smooth and unctious though hard surface, which resists abrasion remarkably. Attention has already been called to the anti-corrosive qualities of aluminum bronze; and as its electrical conductivity is better than that of brass, it is peculiarly well adapted for commutator bars in dynamos. It can be brazed and soldered nearly as well as brass.

CASTING ALUMINUM BRONZE.

Sound, clean castings of aluminum bronze can be safely and regularly made, either in sand molds or against chills, if the proper precautions are taken to avoid: first, oxidation; second, contamination from scum or a cinder composed of oxide of aluminum with a little copper in it; third, depressions, cracks, or strains due to shrinkage; fourth,the shutting in of gas into the castings. The first trouble, oxidation, is due to heating the metal too hot in the plumbago crucible. The copper should not be heated much above its melting point before the aluminum is added, which at first absorbs a great deal of heat and

rapidly thickens the metal, the aluminum being rapidly immersed in the copper to prevent its oxidation. Great care should then be taken in again bringing the metal up to the liquid condition, and the metal should be frequently stirred; for it suddenly heats up by the reaction of the alloying of the two metals, and, unless precautions are taken, will soon bring the temperature up to a white heat, where oxidation will seriously injure the bronze. The metal should have a cover of powdered charcoal to prevent oxidation, but with no other flux over its surface.

The second trouble, contamination from the scum, can be avoided by pouring from the melting furnace or pot into a hot ladle or pouring basin large enough to hold all the metal necessary to fill the mold and to allow the metal to pour out from the bottom of such a receptacle after giving sufficient time to allow the scum to come to the surface. A skim-gate should also be provided for each mold.

The third difficulty is caused by a peculiar red-shortness just after solidification, and also a contraction at solidification which causes the metal to either tear apart or yield and cause depressions in the casting at more favorable spots, if any great resistance is experienced by the metal in contraction. This difficulty is overcome by giving bountiful allowance for the contraction, which can be done in several ways, each best adapted for varying conditions. The cores should be made of a yielding character, using resin or other suitable substance with coarse sand, that will yield to slight pressure. Unyielding iron core rods should be dispensed with as far as possible. "Green" sand cores will give good results in some cases. Other expedients to gain the same ends will be easily suggested by skilled molders.

The troubles due to shrinkage are avoided by having the "risers" or "feeding heads," with flaring openings, large in section, often larger than the castings they are intended to feed, and if necessary refilling the feeding heads, in some cases several times over. In this way the casting will solidify first, drawing metal to supply its shrinkage from the still fluid riser having a level higher than the casting itself, so that the metal will flow down into it. The gates to the mold should be sufficient in number and so arranged that they can be filled with the metal as cold as it will pour and give full castings. The considerable amount of scrap occasioned by the large sectioned risers can be remelted without loss of aluminum, and, indeed, is improved in quality by the process of remelting.

To prevent the shutting in of gas into the castings, dry sand should be used, and the molds should be well vented by the ordinary precautions taken by founders for this purpose. Although it requires skill and experience to successfully carry out the conditions outlined above, sound, clean castings, even of the most difficult sections of aluminum bronze, can be made regularly, and with no more wasters than with ordinary brass, and without the difficulty of a copious liberation of gas at the moment of solidification, as is the case with steel. In fact, aluminum bronze, with its low pouring temperature, is especially applicable for massive and heavy castings.

ALLOYS WITH SMALL PERCENTAGES OF COPPER.

The alloys of aluminum with copper in proportion of from 2% to 15% have already been incidentally referred to. Copper, I believe, is one of the best hardeners of aluminum. The maximum proportion that can be added before the metal becomes too brittle to work depends largely upon the purity of the aluminum. If it contains several per cent of silicon it becomes very brittle with 5% of copper; but with pure aluminum it is still forgeable, with difficulty, with 15% of copper. Even very small percentages of copper added to pure aluminum decrease the blue color of the metal and give a more pleasing yellow-white color to it.

Proportions of a few per cent of copper added to pure aluminum decrease the shrinkage of the metal and give alloys that are especially adapted for art castings. The remainder of the range, from 15% copper up to over 85%, give crystalline and brittle alloys of no use in the arts, and of a grayish-white color, up to 80%, where the distinctly yellow color of the copper begins to show itself.

There is said to be an alloy of 50% copper and 50% aluminum, which is malleable. I have, however, been unable to discover any such alloy in experiments which I have made in this direction, all of the alloys being very crystalline and brittle.

ALUMINUM WITH IRON AND STEEL.

Aluminum combines with iron in all proportions. None of the alloys, however, have proved of value, except those of small percentages of aluminum with steel, cast iron, and wrought iron. So far as experiments have yet gone, other elements can be better em-

ployed to harden aluminum than iron, and its presence is regarded as entirely a deleterious impurity, to be avoided if possible.

The addition of from ⅓ lb. to 2 lbs. of aluminum to a ton of steel gives the advantage of quieting the metal in the mold and producing ingots with much sounder tops, so that the scrap due to crop ends is materially lessened, a saving which much more than pays for the cost of the aluminum added. The amount to be added varies with the character and condition of the steel. With well-melted steel, low in carbon, the proportion of from ⅓ to ½ lb. to the ton seems to give the best results; any larger proportion making the metal pipe and causing excess of crop-end scrap. If the steel be "wild" in the ladle, full of occluded gases, too hot, or oxidized, a larger proportion of aluminum can be advantageously added. Mr. R. A. Hadfield says, I think correctly, that the influence of aluminum appears to be like that of silicon, though acting more powerfully. The same writer, together with Professor H. M. Howe and Mr. Osmund, claims that an addition of aluminum does not lower the melting point of steel. In this my own experience agrees; nor do I believe that aluminum increases to any great extent the fluidity of the steel. So far as my experience goes, steel, with an addition of $\frac{1}{10}\%$ of aluminum, seems to solidify in the molds fully as quickly as steel without the addition of the aluminum. Aluminum seems to take the oxygen out of steel very much in the same way that manganese does, but I am not aware of any advantages gained by using the more expensive aluminum for this purpose.

The addition of aluminum in quantities of from 2 to 3 lbs. per ton is of advantage where the steel is to be cast in heavy ingots which will receive only scant work. Here it seems to increase the ductility as measured by the elongation and reduction of area of tensile test specimens, without materially altering the ultimate strength.

The question as to whether additions of aluminum prevent segregation of impurities in large castings of steel, is still an unsettled one; but I may say that it is now being carefully investigated.

In steel castings the benefit from the use of a small percentage of aluminum, ordinarily in the proportion of from 2 to 3 lbs. per ton, has become widely recognized, and it is being generally used.

The additions of aluminum are almost always made by throwing the metal, in pieces weighing a few ounces each, into the ladle, as the

steel is pouring into it. In cast iron, from 2 to 5 lbs. of aluminum per ton is put into the metal as it is being poured from the cupola or melting furnace. To soft gray No. 1 foundry iron it is doubtful if the metal does much good, except, perhaps, in the way of keeping the metal melted for a longer time; but where difficult castings are to be made, where much loss is occasioned by defective castings, or where the iron will not flow well, or give sound and strong castings, the aluminum certainly in many cases allows of better work being done and stronger and sounder castings being made, having a closer grain, and hence much easier tooled. The tendency of aluminum is to change combined carbon to graphitic, and it certainly lessens the tendency of the metal to chill. Aluminum in proportions of 2% and over materially decreases the shrinkage of cast iron.

The effect of aluminum in wrought iron is not very marked in the ordinary puddling process. It seems to add somewhat to the strength of the iron, but the amount is not of sufficient value to induce the general use of aluminum for this purpose.

The peculiar property of aluminum in reducing the long range of temperature between that at which wrought iron first softens and that at which it first breaks down and becomes fluid, is taken advantage of in the well-known Mitis process. It is for this that aluminum is most used in wrought iron at present.

ALUMINUM AND OTHER METALS.

With the exception of lead, antimony, and mercury, aluminum unites readily with all metals; and many useful alloys of aluminum with other metals have been discovered within the last few years. I venture to prophesy the finding of many more in the near future, as more systematic attempts are made to study the use of aluminum with other metals and metalloids. Of many of these useful improvements that are now subjects of letters patents, for obvious reasons, I will say nothing. The useful alloys of aluminum so far discovered are all in two groups, the one of aluminum with not over 15% of other metals, the other of metals containing not over 15% of aluminum; in the one case, the other metals imparting hardness and other useful qualities to the aluminum, and in the other the aluminum giving useful qualities to the other metals.

The alloy of a few per cent of silver to aluminum to harden, whiten, and strengthen the metal, gives a metal especially adaptable for many fine instruments, tools, and electrical apparatus, where the work upon the tool and its conveniences are of more consequence than the increased price due to the addition of the silver. The silver lowers the melting point of aluminum and gives a metal susceptible of taking a fine polish and making fine castings.

More or less useful alloys have been made of aluminum with zinc, bismuth, nickel, cadmium, magnesium, titanium, chromium, manganese, and tin — these alloys all being harder than pure aluminum; but it is by combinations of these metals, with additions perhaps of copper, lead, and antimony, that alloys of most useful value have so far been discovered. Some are with additions of only 1% to 2% of aluminum.

The addition of from 5% to 15% aluminum to type metal composed of 20% antimony and 80% lead makes a metal giving sharper castings and a much more durable type.

To ordinary brass, the addition of aluminum gives superior strength and better anti-corrosive qualities. Some very marked and valuable qualities have been discovered in the use of aluminum with zinc for various purposes.

The modifications of pewter, Britannia, white metal, Delta metal, and the like, with additions of aluminum, have shown very useful qualities, and will add very considerably to the demand for aluminum in the near future.

CLAY AS A SOURCE OF ALUMINUM.

Evidently contrary to the understanding of the case by many people who have written us with brilliant claims of rich mines, aluminum has never been found in nature in the metallic state; and yet the general statement made by Professor Richards is true, that "there is no other metal on the earth so widely scattered, and that occurs in such abundance." This statement, however, has been interpreted by the public to the effect that therefore all these varied minerals containing aluminum are equally applicable as ores from which to extract the metal; especially have they considered that clays, silicates of aluminum, are the specially chosen ores for the production of aluminum. A consideration of the comparative constituents of clay with those of the minerals given below shows the disadvantage of the rich-

est of clays, as aluminum ores, as compared with the richer and purer oxides, fluorides, and sulphates, which minerals are now used as ores of aluminum.

Bauxite ($Al_2H_6O_6$), soft and granular; with 50% to 70% oxide of aluminum and with only a few per cent of accidental impurities besides the water of hydration.

Corundum (Al_2O_3), very hard and crystalline, specific gravity 3.909.— With 93% alumina and ordinarily very free from impurities, but so hard and crystalline, and withal so valuable for other purposes, as not to be at present used as an aluminum ore.

Diaspore ($Al_2O_3H_2O$), hard and crystalline; specific gravity, 3.4.— With 65% to 85% alumina and ordinarily very pure.

Cryolite (Al_2Fl_66NaFl), specific gravity, 2.9.— With 40% aluminum fluoride and 60% sodium fluoride.

Aluminite ($Al_2SO_69H_2O$), specific gravity, 1.66.— Containing some 30% of alumina in a condition to be cheaply purified by solution, filtration, and roasting.

Gibbsite ($Al_2O_33H_2O$), stalactitic · specific gravity, 2.4.— Containing about 65% alumina.

In comparison to these, the clays vary from tri-basic silicates of alumina to pentacid silicates, minerals with at best 65% alumina and 35% silica; while the more common clays contain from 50% to 70% silica and only from 50% to 35% alumina. Pure kaolin contains 39% alumina, carrying about 20% aluminum, with 40% silica, and 14% water. It has a formula of $Al_2Si_2O_72H_2O$. Now silica is much easier reduced than alumina, and by all the methods of reduction this large percentage of silica must be separated from the alumina before the reduction is commenced, else a large percentage of energy used in reduction will be expended in reducing a troublesome impurity, instead of in reducing the alumina to aluminum. The true value of clay as an ore of the metal is evident, therefore, in comparison with the richer and purer ores that have only accidental amounts of iron and silicon, up to perhaps 10%, to be removed before being submitted to the reducing operation.

There seems to be one fact favorably prominent, however, in the prospect of fat clays like the kaolins being used as aluminum ores — that is, that concentrated cold sulphuric acid dissolves the alumina out of most clays, leaving the silica insoluble. Although this fact has not yet, to my knowledge, been made use of on a commercial scale, still in the future, when there is a large demand, this method may make clays available as ores of aluminum.

PREPARING ALUMINUM ORE FOR REDUCTION.

Bauxite is the mineral most used at present for the manufacture of alumina, and it probably will continue to be the most economical ore, for the reason that it is soft, easily ground and easily decomposed to separate the impurities of silica and iron. The mineral occurs in great abundance in the South, in Tennessee, Virginia, North and South Carolina, Georgia, Alabama, and also Arkansas. Very pure bauxites can be laid down in quantities in Pittsburgh at a cost of between $9 and $10 per ton, and with only the cost of mining and transportation can be put on cars nearest the mines in many cases at a cost of less than $2.50 per ton.

The general method of purification of the ore is to calcine the bauxite with just sufficient sodium carbonate to form sodium aluminate ($Al_2O_3 3Na_2O$). The temperature must be kept below the melting point (the aluminate being formed at a temperature lower than the melting point of the mixture), else silicate of aluminum is formed. The mass is well stirred to insure the complete displacing of all the carbonic acid and the combination of the sodium carbonate with the alumina. A ready test of the completion of the reaction is that portions taken from the mass no longer effervesce and evolve carbonic acid upon treatment with acid. The incinerated mass is taken out of the furnace, ground and lixiviated with hot water, which takes the sodium aluminate into solution, leaving the silica and iron insoluble. The clear supernatant sodium aluminate solution is siphoned off, and the alumina is precipitated with carbonic acid gas. This forms sodium carbonate, which remains in solution, while the alumina settles out to the bottom of the tank. This is afterwards washed with hot water and dried.

The same general method of treatment is applicable to the aluminum oxide minerals for their preparation; the difficulties to overcome being in grinding the minerals, because of their hardness and the formation of the sodium aluminate at a low enough heat to prevent the sodium silicate forming. It may be that these minerals had best be taken into solution as sulphates, and thereafter treated as the native sulphates by a red heat to drive off the sulphuric acid, leaving pure alumina as a residue. With proper apparatus to condense and save the sulphuric acid, such processes may not be excessively expensive. However, neither this method of manufacture of the

sulphates from clays or from native oxides, nor the method of manufacture of alumina from the sulphate by roasting, have so far found favor commercially in comparison with the soda carbonate fusion method for the preparation of the oxide. The sulphate of aluminum melted with sulphur gives off sulphuric acid gas and transforms the alumina into sulphide. This reaction has been made available in one of the methods of manufacture of aluminum from sulphide by the aid of electricity; the sulphide being afterwards decomposed by electrolysis.

COMPOUNDS OTHER THAN ALUMINA FROM WHICH ALUMINUM HAS BEEN REDUCED.

Aluminate of soda is made from cryolite by the incineration of finely ground cryolite with an intimate mixture of chalk or finely ground carbonate of lime, with enough ground coke to keep the mixture porous. Soluble aluminate of soda is formed; insoluble fluoride of lime remains as a waste product, together with carbonic acid which is evolved. The precipitation of the alumina from the aluminate of soda is carried on by the same method as previously described.

Aluminum sulphide, a yellow, infusible salt, containing 36% aluminum, is produced from alumina by the reaction of carbon bi-sulphide at a high heat in the presence of carbon. It is also prepared, as explained, by the fusion of aluminum sulphate in the presence of sulphur. It is a rather unstable compound, being decomposed by standing in moist air into alumina, with the evolution of sulphuretted hydrogen.

The chloride of aluminum was for a long time the chief salt from which the metal was produced, for the reason that it had been found that metallic sodium reduced the metal from this salt the easiest. For a long time the only practical way of cheapening the manufacture of aluminum by this method was to cheapen the manufacture of sodium and reduce the expense and improve the quality of the aluminum chloride. This proved a difficult task.

The salt varies from pure white, when pure, through the yellows to a brick red when largely contaminated with ferric oxide. It is produced by the action of chlorine gas upon an incinerated mixture of alumina with tar or some oil that will, on burning out during the incineration, leave its coke in intimate mixture with the alumina.

The double chloride of aluminum with sodium is produced if a supply of salt is added to the mixture and it is treated with chlorine gas. The expense and difficulties connected with the manufacture have proven very large, and the chlorine produced has to be very carefully made to keep it free from iron. The difficulties connected with the generation and use of chlorine gas on a commercial scale are found to be very great and the deterioration of the apparatus to be very serious.

The native fluoride of aluminum and sodium, the mineral cryolite, has been used in several processes as the ore for the production of aluminum. It, however, contains too much silicon and oxide of iron to make pure metal; for, as before said, in all the methods so far devised, or which seem likely to be devised in future, the agents that serve to reduce the aluminum to a metallic state will surely reduce all the silicon and iron from their oxides that may be present at the same time or rather previous to the reduction of the aluminum. Pure aluminum fluoride (Al_2F_6) is produced by the action of sulphate of aluminum on cryolite, sulphate of soda being the by-product, according to M. Grabau. Aluminum fluoride can also be produced by the action of hydrofluoric acid on alumina. It is not such an expensive or difficult salt to prepare as the chloride, and is the compound from which aluminum is produced in many of the later and more successful processes. Metallic sodium reduces the fluoride of aluminum with the same facility with which it acts upon the chlorine compounds.

METHODS OF ALUMINUM MANUFACTURE.

Aluminum cannot be reduced from its oxide by the aid of carbon as a reducing agent, because the temperature to which the intimate mixture of the solid carbon and the alumina has to be raised can only be attained by the highest heat of an open-hearth furnace or in the electric furnace — a temperature at which the aluminum reduced cannot itself be accumulated into a molten liquid mass, and can only be retained by cloaking it with a more stable metal like iron or copper. It is for this reason that the Cowles Electric Smelting & Aluminum Company are not able in their electric furnace to manufacture commercially pure aluminum, nor the Heroult people to manufacture the metal from their process of reduction, where they electrolyze pure molten alumina, which requires a high electrically produced heat to

melt the oxide. None of the other salts are susceptible of being reduced by carbon at much lower temperature than the oxide, so far as yet discovered.

Debarred from using carbon as the reducing agent under the ordinary conditions which make it the practicable and economical reagent in most metallurgical operations, the advantages of other stronger reducing agents have been carefully tried. So far only one has proven commercially available, although there are many other agents capable of reducing the metal from its oxide. Metallic sodium reduces the metal from its chloride or from its fluoride salts with ease. Methods based upon the use of sodium as the reducing agent have until lately given not only the purest but the cheapest aluminum. These methods, however, of late, have been succeeded by the cheaper and more direct processes of electrolysis of some of the aluminum salts or of the pure oxide.

THE HISTORY OF ALUMINUM PRODUCTION.

So far as history informs us, Wöhler in 1827 first reduced metallic aluminum by the aid of metallic potassium as the reducing agent from aluminum chloride. The metal was a dry powder in a finely comminuted state; it was very impure, and was only a metallic curiosity. Deville, twenty-seven years later, in 1854, was the first to produce the metal in any quantity, or with any degree of purity.

It is curious to note that the first pure aluminum made was by electrolysis; both Bunsen and Deville reduced the double chloride of aluminum and sodium by electricity generated by galvanic batteries. But as at that time the dynamo was still a machine of the future, electrolysis was soon abandoned for the sodium process by the successful concerns in the manufacture of the metal, although continued experimental efforts were made with electricity from that time to this. The first aluminum made in 1855 was valued at $90 per lb. In 1857, with the development of the sodium method of reduction, the price was lowered to from $28 to $32 per lb. In 1860, the price was again lowered to about $17 per lb., and from 1862 to 1887 the price ranged from $12 per lb. upward, according to purity. In 1887 the price was reduced to one pound sterling per pound avoirdupois; and it was at this price that the first metal made was sold by the new concerns built during that year. In 1889 the Pittsburgh

Reduction Company reduced the price to $2 per lb. As the English works of the Pittsburgh Reduction Company commenced in 1890 to sell the metal in England at five shillings ($1.21) per pound, I presume that future writers will record a further drop in the price of the metal in 1891.

About 1857 the famous works at Salindres were established, which were under the proprietorship of Pechiney & Company for many years, and, until within the past three years, enjoyed not only the reputation of making the best, but the largest, amount of aluminum produced in the world. The care and skill shown, and the ingenious devices and precautions taken by the firm to prevent impurities in the metal by the cumbersome and expensive sodium process in which there were so many opportunities for the addition of impurities, were worthy of the highest praise. In 1860 Sir I. Lowthian Bell, with a brother, started works in Newcastle-on-Tyne, which were abandoned in 1874. They manufactured by the sodium process. From 1874 until 1882 the French company at Salindres was the only concern making pure aluminum.

In 1882 Webster organized the "Aluminum Crown Metal Company" at Hollywood, near Birmingham, England, and by cheapening the production of aluminum chloride soon developed a successful concern. This was further strengthened by the improvement of Mr. H. Y. Castner, an American chemist, who, in 1886, patented improvements for producing a more intimate mixture of the carbon with the caustic soda in a state of fusion by means of a carbide of iron, in this way cheapening by more than one half the cost of manufacture of metallic sodium, which had been $1 per lb. This concern was organized under the name of the Aluminum Company, Limited, and put up a large and expensive plant at Oldbury, near Birmingham, England. These works were started at the end of June, 1888, and they have been manufacturing up to within the past six or nine months. In common with the other manufacturers by the sodium process, they have been working at great disadvantage since the advent of the more successful electrolytic processes.

Early in 1888 the Alliance Aluminum Company started works at Wallsend-on-Tyne, England, using a process which was an innovation upon the Deville sodium process by using the fluoride or the double fluoride of aluminum and sodium cryolite as the compound to be

reduced instead of the chloride or the double chloride of the metal. Professor Nette, the managing director of the concern, also had a process for producing metallic sodium cheaply by allowing fused caustic soda to trickle over incandescent charcoal in a vertical retort. Some very excellent aluminum was produced at this works; they became involved in a lawsuit, however, with the Aluminum Company, Limited, and the newer processes coming up caused them also to close their works, which have now been shut down for over a year.

ALUMINUM PRODUCTION BY ELECTRICITY.

In spite of the broad claims of the Cowles Brothers to the use of electricity for metallurgical purposes, the first actual reduction of aluminum in a metallic state on a practical scale by Deville in 1854 was, as we have seen, by the aid of electricity, electrically decomposing the chloride. Even then the idea was old, for Sir Humphry Davy in 1810 publicly described the successful experiment made in 1807, in which he connected the negative pole of a battery of 1,000 double plates with an iron wire which he heated to a white heat and then fused in contact with moistened alumina, the operation being performed in an atmosphere of hydrogen. The iron upon analysis was found to be alloyed with aluminum.

Bunsen in Germany and Deville in France, in 1854, each electrolyzed the double chloride of aluminum and sodium. Le Chatelier obtained English patent No. 1,214 in 1861, and Monckton, in 1862, English patent No. 264 for the reduction of aluminum by aid of electricity. In fact, Richards says that the Monckton patent "proposes to pass an electric current through a reduction chamber, and in this way to raise the temperature to such a point that alumina will be reduced by the carbon present," showing that not only was the use of electricity for reducing aluminum old, but that the idea of the electric furnace was twenty years old at the date of the first of the Cowles patents in 1885.

Richards, in his work on aluminum, mentions and gives the published authority in each case of the processes for reducing aluminum with the aid of electricity; of Gaudin, 1869; Kagensbusch, 1872; Berthaut, 1879; and Gratzel, 1883.

The newer pure aluminum processes using electricity of Hall, Heroult, and the Bernard Brothers, with the help of Minet, together

with the alloy processes of the Cowles Brothers and of Heroult, are the only ones that are now being worked upon a commercial scale, so far as I know, though perhaps the meritorious inventions of Mr. Grabau may have been reduced to practical working of late. Of this I am uncertain, or of what is being done by Herr Saarburger at Hemelingen, near Bremen. I only know that we no longer hear of the Aluminum & Magnesium Fabrik Company's aluminum in the competition of the markets, nor of any metal made by the sodium process.

Besides these, there have been a host of other electrical attempts and experiments for the manufacture during the past two years, since the success of some of the other companies using electricity became known.

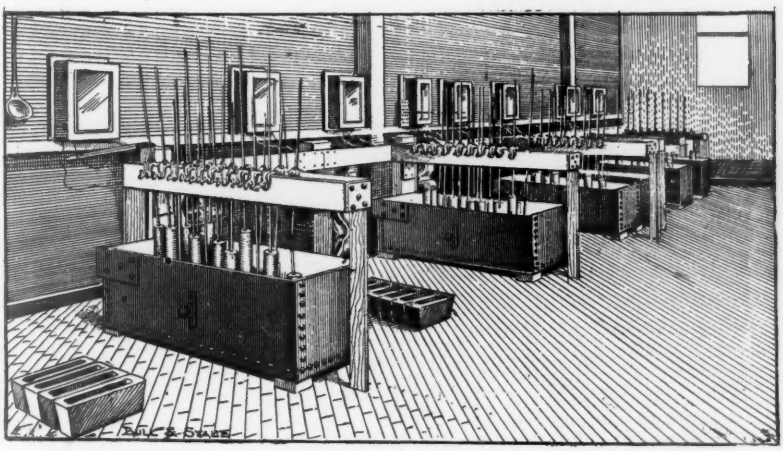
THE HALL PROCESS OF ALUMINUM PRODUCTION AND OTHER ELECTRIC PROCESSES.

The Hall process of manufacturing aluminum is owned by the Pittsburgh Reduction Company, who have, in addition to 390 electrical horse power at work in Pittsburgh, another plant of about equal size at Patricroft, Lancashire, England, the Pittsburgh works commencing to manufacture in November, 1888, and the English works in July, 1890.

The Hall process consists in electrolyzing alumina dissolved in a fused mixture of fluorides of aluminum and sodium or of fluorides of aluminum and potassium, or, in fact, Mr. Hall has covered in his letters patent No. 400,667 a fused bath in which the alumina is dissolved in the fluoride of aluminum, together with the fluoride of *any* metal more electropositive than aluminum.

As the Pittsburgh Reduction Company uses the process, it places the mixture of fluoride salts in a row of carbon-lined iron tanks placed in series. The pots, together with their carbon linings and the reduced metal in the bottom of the pots, become the negative electrodes or cathodes. The positive electrodes or anodes are a series of 3-inch diameter carbon cylinders, attached by ⅜-inch copper rods to the copper conductors by the aid of suitable binding screw clamps. The current of 5,000 amperes and fifty volts in one series, and of 2,000 amperes and 20 volts in the other series, is turned on, and the mixture is melted by the heat caused by the resistance offered to the current by the fluoride mixture. In less than

two hours' time the mixture becomes fluid, and alumina is added. The electrolyte then becomes a much better conductor, "the resistance of the pot" goes down to a normal one of about 8 volts, and the operation of electrolysis commences. The alumina in solution, or, as some claim, the fluoride of aluminum, is decomposed; the metal, being heavier than the electrolyte, sinks to the bottom of the pot, and the oxygen goes to the positive carbon electrode, uniting with a portion of the carbon and escaping as carbonic acid gas; or, as is maintained by some, the aluminum of the fluoride of aluminum is deposited, and



REDUCING POTS — PITTSBURGH REDUCTION COMPANY'S PROCESS.

the fluorine attacks the dissolved oxide, reforming fluoride of aluminum, and thus maintaining the integrity of the original electrolyte bath, the oxygen going off, as in the other case, at the positive electrode.

While the actual fact as to which reaction takes place is not essential to the validity of the Hall patents, and the Pittsburgh Reduction Company makes no claims regarding the matter, it is our belief that the compound electrolyzed is alumina. I may say, in this connection, that this is the view of Professor J. W. Langley, Professor Richards, and of all the other metallurgists who have had experience with and have given the actual metallurgical operations careful study.

Among the reasons for our belief are the heat of formation of alumina, 391,600 calories; the fact that it requires only 2.8 volts to decompose it; the probable fact that the heat of formation of the aluminum fluoride is very considerably greater; the fact already established, that it requires a very much higher voltage than 2.8 to decompose the electrolyte that we use; and the fact, already mentioned, that when the bath gets out of alumina the resistance rises considerably (ordinarily about four volts), and that the heat rises rapidly in the pot until the electrolyte itself begins to decompose, and stifling white fumes of hydrofluoric acid begin to be given off.

Again, fluorine displaces oxygen in alumina; hence we reason that aluminum fluoride is a stronger compound than alumina. Sodium reduces aluminum fluoride—the basis of the Grabau process. Ergo, sodium fluoride is a stronger compound than aluminum fluoride. Hence, in a bath containing sodium fluoride, aluminum fluoride, and alumina, in nearly equal proportions, the order in which they will be decomposed by an electric current of graduated intensity, or in conditions similar to the Hall bath, will be alumina, aluminum fluoride, and sodium fluoride. Again, the electro-motive force required to decompose compounds is in proportion to the heat evolved in the formation of electro-chemical equivalent weights of the compounds; and sodium fluoride is thermally much greater than $\frac{1}{6}$ of a molecule of aluminum fluoride, or of a molecule of alumina.

According to my understanding of the case, the difference between the Hall process and the Heroult alloy process is this: Hall electrolyzes alumina made fluid at a lower temperature by dissolving it mechanically in a fused fluoride solvent, lighter than aluminum, which will not corrode the metal, and above all will not be itself decomposed by the electric current (or at least will not stay decomposed), and which is a sufficiently good conductor of electricity to allow the temperature of the molten bath not to reach much above the melting point of the metal. In the Heroult process they electrolyze alumina made fluid by the intense heat of the electric arc, at a temperature at which the metal has to be protected by being alloyed with copper or iron in order to retain it.

DETAILS AND ADVANTAGES OF THE HALL PROCESS.

In the practice of the Hall process the heat is retained in the molten bath by a covering of finely powdered carbon on the surface of the molten mixture. On top of this carbon raft the powdered alumina is placed, and when the voltmeter attached to each pot shows a rising resistance, the pot-tender stirs in more heated ore from the surface of the pot. The carbon soon comes to the surface, when a fresh supply of ore is placed on it. The feeding is thus easily made continuous, and as the electrolyte remains constant it only requires tapping the metal off — or, as is rather crudely but very satisfactorily done, dipping the metal out in cast-iron ladles, and skimming the electrolyte back into the pots with the carbon rods — to make the entire operation continuous. The pots are run for months at a time. The following are the chief advantages of the continuity of the process:

1. *Purity of the Metal.*— After the first run of metal is cast, carrying with it all the iron and silica, or rather the reducible impurities of the electrolyte, the only other sources of impurity are in the pure alumina added and in the ash of the positive carbon electrodes, which are worn away in the proportion of a little less than weight of carbon to the weight of metal produced.

2. *Saving of Material.*— The loss of metal and ore in a finely divided state in the bath, which occurs when a shut-down is required, is avoided. To be sure, this loss can be largely avoided by re-melting again; but in melting down the metal in a finely divided state it is found to be almost entirely re-dissolved. As continuously carried on, the loss of metal is practically nothing, every particle being reduced; undoubtedly it is often reduced more than once by being re-dissolved before settling through the bath to the metal below, when the ore gets out of the electrolyte and it becomes acid. At the same time, as there is no slag or other waste product, solid or liquid, evolved, and as the gases can carry off none of the aluminum, all of the aluminum in the ore added is finally brought out in ingot metal, a result that is seldom experienced in the reduction of metals from their ores.

3. *Economy.*— The original heat of the electrolyte is constantly maintained, and the only supplies needed are the constant electric current, the alumina ore and fresh carbon electrodes to replace those worn out, with only occasional additions of fresh electrolyte to replace

the small loss of that taken out with the ingot metal or that which has become decomposed by the workmen carelessly letting the pots get out of ore. This decomposition of the electrolyte means an infusible "cake," as the workmen call it, settling to the bottom of the pot and filling it up. When the pots are not skillfully run, or more easily decomposing electrolyte mixtures are used, this accumulation shortens the run of the pot, and also decreases the out-put. In the regular practice of the Pittsburgh Reduction Company there is practically no decomposition of the electrolyte, and a pound of aluminum is made with an expenditure of about 22 electrical horse power per hour.

This electrical energy expended in heat is not very expensive. Supposing water power to be used at a cost of $12 per horse power per annum, allowing 25% for loss in converting mechanical into electrical energy, and supposing 75% of this energy to be converted into heat, Professor Richards has calculated the heat generated by 1 horse power during one year as 8,400,000 heat units.

The Hall process can be successfully carried on entirely independent of carbon, using a thick iron or copper tank, and either iron or copper electrodes. The deposition of the metal is nearly as large as with the use of carbon electrodes; but it is, of course, alloyed with copper or iron from the metal worn away from the positive electrode.

The Pittsburgh Reduction Company has made alloys of aluminum with iron and copper by this process similar in character to the alloys produced by the Cowles and Heroult alloy processes.

THE HEROULT AND MINET PROCESSES.

Almost at the same time that Hall invented his process for manufacture of aluminum, in the early part of 1886 (his first patent application dating July 9, 1886), M. Pierre Heroult commenced operations, and afterwards took out English patent No. 7,426 of 1887 for fluxing alumina with cryolite. The bath was put into a graphite crucible, which served as a negative electrode, and this was put inside a larger crucible, the space between the two being filled with graphite, and the carbon positive electrode being immersed in the fused bath. The ideas of M. Heroult and Mr. Hall at the start were very nearly identical. M. Heroult attempted to obtain an American patent, and was declared in interference with Hall; and, after the testimony as to dates of invention and of the application for patents, M. Heroult withdrew in

favor of Mr. Hall. This process was practically abandoned for a while by M. Heroult in favor of his very successful alloy process of electrolyzing and reducing molten alumina; but since 1889, when a growing demand sprung up for pure aluminum, and the success of the Hall process became known, I understand that two concerns have begun working under the same principles — the Aluminum Industrie Actien Gesellschaft, at Neuhausen, Switzerland, and a concern at Froges (Isère) in France, called the Société électro-métallurgique de France. I have seen some very pure and excellent metal from the Swiss concern.

The process commonly called "the Minet process," as developed and used at the works of the Bernard Brothers at Creil, Oise, France, consists in electrolyzing a mixture of sodium chloride with aluminum fluoride, or with the double fluoride of sodium and aluminum, their English patent dating July 18, 1887, No. 10,057. This company, I understand, have been doing successful work, and are now putting on the market aluminum of good quality. Thus it will be seen that there have developed apparently three separate electrolytic processes for the manufacture of pure aluminum at about the same time, all of which are working on about the same lines. These, together with the already much-written-about Cowles and Heroult processes for the manufacture of aluminum alloys, have for the past two years distanced all competitors manufacturing by the aid of metallic sodium, and are today in the possession of the aluminum market of the world.

FUTURE PROCESSES OF ALUMINUM PRODUCTION.

And now I will close with a few remarks upon the prospects and possibilities of the future — a subject in which, as President of the Pittsburgh Reduction Company, I am both financially and technically very much interested.

First, let me preface what I have to say by stating that I am not at all afraid of any new process of which the first we hear is the blast of trumpets and a general outcry through the newspapers of the very low cost at which the metal can be made, given in figures exact to a cent. I feel confident that either the inventor of such a process, or his friends, the company promoters, have so little sagacity and business sense that they will fail, even if they have a good thing; or else that they are simply attempting to further deceive the public and

prospective investors with delusive prospects, which, if well founded, would have been the very reason for keeping the matter quiet until they had become organized, and secured their capital and protection, so far as possible, by letters patent. If an inventor has a meritorious process for the manufacture economically favorable to the processes now in vogue, the method would have to be so simple that he would be able easily to prove it, and then he would have no trouble in securing capital to help him. The first thing any sagacious capitalist would then do would be to insist that cost prices be kept quiet, at least until it should be proved on an actual manufacturing scale just what cost prices were. For very often a most delusive difference is found to exist between the theoretical cost price and actual cost price, as may be proved by the books of almost any well organized manufacturing concern.

THEORETICAL COST OF MANUFACTURE BY ELECTROLYSIS.

Theoretically, the cost price of the manufacture of aluminum by direct electrolysis has already been brought down very low as compared with the cost of the more complicated processes of a few years ago. The cost per pound is about as follows:

2 lbs. of alumina (Al_2O_3, contains 52.94% Al_2) at 3 cts.	$ .06
1 lb. of carbon electrode at 2 cts.	.02
Chemicals, carbon dust, and pots	.01
22 E. HP. exerted one hour, water power being used	.05
Labor and superintendence	.03
General expense, interest and repairs.	.03
Total.	$ .20

I would say here that while the actual cost of the metal produced by the Pittsburgh Reduction Company, or any other of the concerns mentioned as actually putting aluminum in limited quantities on the markets today, are nothing like these figures as a total, at the same time, as the most economical methods are used, figures approaching these will undoubtedly be attained; and, moreover, improvements in new processes will in many cases probably be equally applicable in reducing costs by the present electrolytic methods. As stated before in this paper, no process can be devised that will give less loss of ore than that of the Hall process, where it is practically nil, nor

is it probable that any other method can be devised that is able to give purer metal than that made by the Hall process. Analyzing the items of cost given above, the ore will probably be the greatest item of expense in any successful process, and surely the oxide, alumina, is not only the richest and most easily prepared pure ore, but will prove one of the cheapest, if not the cheapest, of compounds from which to extract the metal. Quite surely no difference here in the art will make an insurmountable barrier of cost for the electrolytic processes now in use to compete against. The expenditure for other reagents than the ore, for carbon, and for chemicals, is now less than 5 cts. per lb., with the Pittsburgh Reduction Company, and in the estimate can fairly be reduced to 3 cts. per lb. for a large plant, with most favorable arrangements made for its supplies. In the item of electrical power there certainly may be room for a large curtailment of cost; but, even should this expenditure of electrical power be lessened one half, or entirely done away with, heat alone being substituted as the energy for reduction of the ore, it will be difficult to conceive of a method that would not require a cost of at least one cent for this heat, which would be a saving perhaps of 4 cts. per lb. upon this item of electrical power. However, I feel confident that should such processes be devised, the increased expenditure for chemicals and other reagents besides the amount quoted as necessary for the Hall electrolytic process will nearly, if not quite, counter-balance the saving in electrical energy expended in the Hall process.

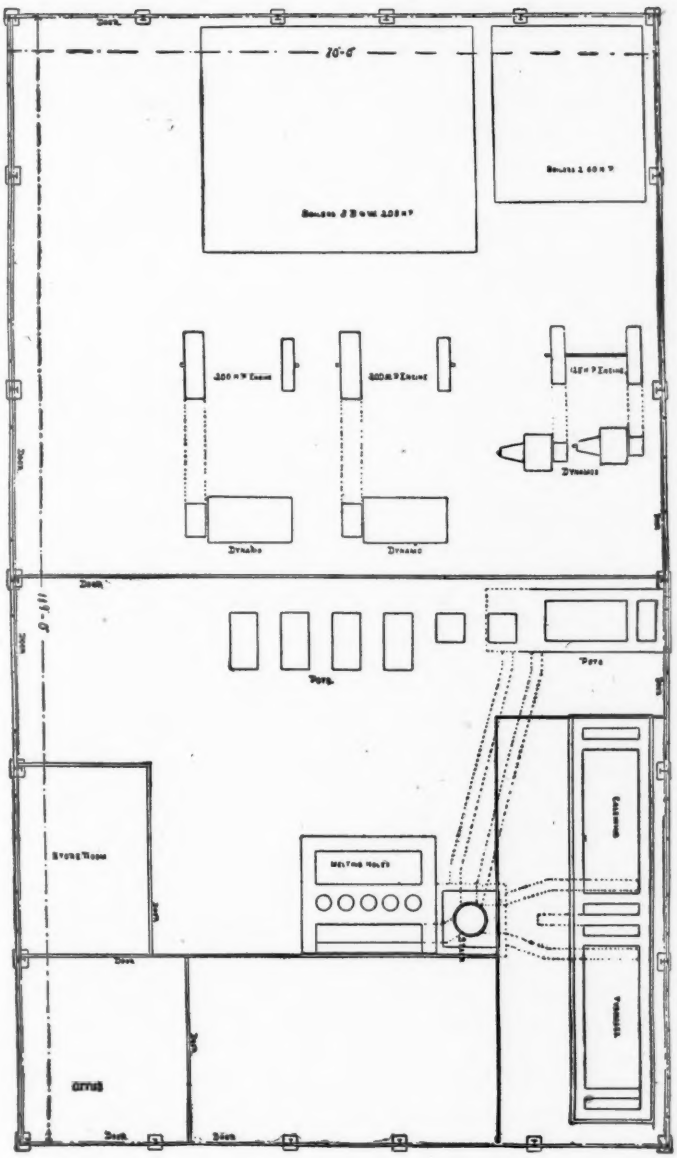
In the items of labor, superintendence and general expense, interest and repairs, there may be material saving made by a process yielding metal more rapidly than by the comparatively slow electrolytic process. But the plant required by the Hall process is very simple — especially if located upon water power — and the repairs are very small in proportion to the out-put. It will be doubtful, therefore, if a saving of more than 3 cts. per lb. can be made, or one half of the total estimated as necessary for the manufacture of aluminum by the Hall process. Thus the total saving probable, or, I think I am almost justified in saying, even in these days of wonderful inventions, possible, is only about 7 cts. per lb. over the cost of the Hall process. A greater saving than this may perhaps be made if some bright artist shall be able with Aladdin's lamp to rub the clay bank with his magic wand and extract "the silver from the clay" by his incantations; or, perhaps,

more soberly, some one may find a method of reducing aluminum from some of its compounds as a by-product, the expense of which shall entirely or mainly be borne by the other valuable products made.

POSSIBLE COMPETITORS OF THE ELECTROLYTIC PROCESS.

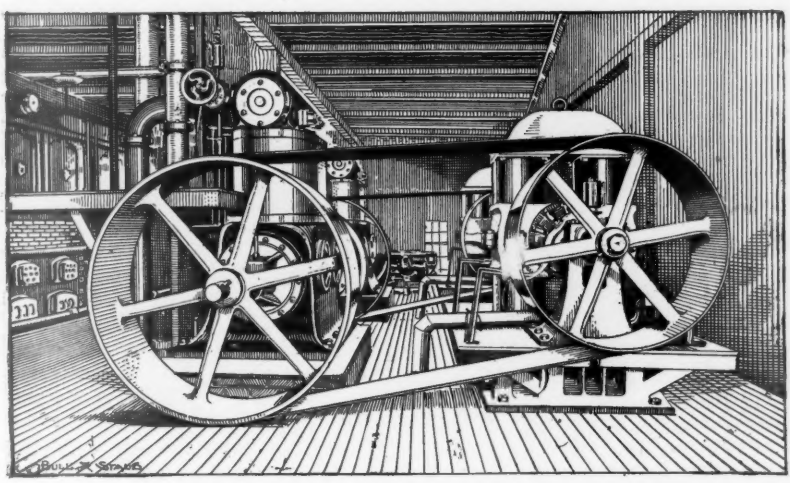
In this connection, an ingenious method has been devised to electrolyze the sulphide of aluminum, or the double sulphide of aluminum and sodium, in a tank, closed and suitably insulated, and connected with a powerful electric current. The tank is filled with charcoal, covered with alumina, or, in case the double sulphide is to be made, with a mixture of alumina and some sodium salt. The tank is heated to incandescence by the electric current, and fumes of sulphur are forced into the tank. An atmosphere of bi-sulphide of carbon is produced; the excess is carried away by a condensing pipe, and is calculated to yield revenue enough to pay for the entire operation, which consists further in reducing the sulphide of aluminum produced by a portion of the bi-sulphide of carbon acting upon the alumina in the presence of the heated carbon. The sulphide of aluminum is electrolyzed in the lower part of the tank, the molten metal going to the bottom, where it is afterward tapped out, The evolved sulphur again attacks the hot coal and produces bi-sulphide of carbon. This process looks very pretty on paper, but, unfortunately, it has not thus far proved financially successful.

The only method which seems at all likely to supersede the electrolysis of alumina as the most economical method of manufacture of aluminum is some variation in the condition of reduction (such as performing under pressure or the like). The oxide, or an equivalent aluminum compound, would have to be cheaply prepared, by the aid of carbon at a much lower temperature than is now possible by the means already tried. If such a feat could be accomplished, the changed conditions under which the carbon was to work not being too expensive to attain, and the reduction being accomplished rapidly enough to admit of the process being used upon a large commercial scale, then the electrolytic methods of manufacturing aluminum would have to be relegated to the same fate that has already overtaken the sodium method of reduction. But, in the light of what I have already said, I venture here to predict a long life and a happy one yet for the electrolytic methods of manufacture of aluminum.



PLAN OF THE PITTSBURGH REDUCTION COMPANY'S WORKS.

In closing, I wish to acknowledge my indebtedness to Professor Joseph W. Richards, of Lehigh University, not only for personal statements and suggestions, which I have embodied in this lecture, but also for data from his admirable book on aluminum. It is the first work on the subject printed in the English language, and I prophesy that it will always hold an authoritative position among the best treatises on the metallurgy and properties of aluminum, a place akin to that held by Percy's "Metallurgy of Iron and Steel."



DYNAMO ROOM — PITTSBURGH REDUCTION COMPANY.

ON THE CONTRAST IN COLOR OF THE SOILS OF HIGH AND LOW LATITUDES.

By W. O. CROSBY.

THE general contrast in color of Northern and Southern soils has attracted my attention for many years; and six years ago I suggested an explanation of this difference, which is evidently due to the condition of the ferric oxide, in a communication to the Boston Society of Natural History,[1] from which several paragraphs may be advantageously quoted as an introduction to the present paper:

The prevailing difference in color between the soils of the North and South is an unquestionable fact, and must be familiar to many travelers; and yet, but few geological writers have even mentioned it, and, so far as I can learn, no explanation of it has heretofore been proposed. In all latitudes the most superficial detritus, the true agricultural soil, is, in a large measure, distinctly carbonaceous, or the organic matter has at least been sufficient to more or less completely discharge the brown, yellow, and red colors due to the ferric oxides. But in the surface soil to a considerable extent, and in the subsoil generally, the ferric oxides are still the predominant coloring agents. Now throughout the Northern States and Canada the soils, where their colors can be ascribed to ferric oxide, are generally, almost universally, brownish or yellowish, but not distinctly red. The only important exceptions are where the red soil results from the disintegration of a red rock, or is itself geologically old. Thus, the red color of the soil on the Triassic areas, and of the clays at Brandon, Vermont, and Gay Head, does not belong to the present or any recent period, but is due to the peroxidation of iron in Triassic and Tertiary times. On the other hand, one of the most striking features of the scenery of the Southern States, especially for Northern eyes, is the bright red color of the soil, and the general predominance of this color over the brownish and yellowish tints. This begins to be noticeable in the latitude of Southern Pennsylvania, and becomes more and more marked as we cross Virginia into the Carolinas; while in the West Indies and South America the redness of the soil is even more intense and universal than in the Southern States. So far as I have been able to learn by reading and inquiry, this difference in color between the soils of high and low latitudes is more or less distinctly observable in all longitudes, and in the southern as well as the northern hemisphere.

The brown, yellow, and buff colors, so characteristic of Northern soils, are undoubtedly due chiefly to the yellow ferric hydrates, like göthite, limonite, and xanthosiderite; while the red color of Southern soils, although commonly attributed to hematite, is probably in many, if not most, cases due to the red ferric hydrate, turgite. The main question, then, Why are Northern soils yellow and Southern soils red? is really equivalent to, Why is the ferric oxide in Northern soils highly hydrated (göthite, limonite, etc.), while that in Southern soils is only slightly hydrated (turgite), or anhydrous (hematite)?

---

[1] Proceedings of the Boston Society of Natural History, Vol. XXIII, pp. 219–222.

It is manifestly impossible to answer this question by correlating the difference in color with a difference in the rocks of the two regions; for, while the red clays of the South are found on nearly all geological formations, they appear to have their best development on the primary or crystalline rocks, and these are indistinguishable from the similar rocks of the North. But a satisfactory solution is, I think, found by correlating the color-difference with the one physical feature upon which all the other contrasts between the North and South depend — the climate. In other words, the difference in color depends upon a difference in temperature. It is well known to chemists that ferric hydrate, the coloring agent of Northern soils, is dehydrated at the temperature of boiling water; and it seems probable that a partial, if not complete, dehydration may result at much lower temperatures, if unlimited or geologically long time is allowed. And, in this connection, it is important to observe that the surface soils of the South attain at times a high temperature, and that in both regions, but especially in the South, the detritus is, quite certainly, chiefly of preglacial origin. The detritus of the South, it is well known, is, except on the flood-plains of the streams, chiefly sedentary, often retaining almost perfectly the structure lines of the rock from which it is derived; while the débris covering the rocks in the North is almost wholly transported, consisting of the modified and unmodified glacial drift. Hence it is evident that the characteristic colors of the North and South are approximately coterminous with the sedentary detritus and drift. But it seems impossible to ascribe the color-difference to glaciation; for wherever in the North we find sedentary soils, either post or ante-glacial, as in the case of trap dikes which have been decomposed to a considerable depth below the surface of the inclosing rocks, the colors are brown and yellow, never red.

Although it seems not to have attracted general attention, my observations show that frequently, if not always, the red color of the Southern soils is a merely superficial phenomenon, being most strongly marked at the surface, and gradually changing to yellow at a moderate depth. This fact, if fully established, will strongly corroborate the view here proposed, that the solar heat is the principal cause of the dehydration of the ferric oxide.

Nearly all soils originate, directly or indirectly, in the decay of the silicate minerals of the crystalline rocks, in which the iron is very largely in the ferrous state. And it is well known that the meteoric waters percolating through the rocks not only introduce the carbon dioxide, which is the chief agent in the kaolinization of the anhydrous silicates, but also the free oxygen required for the peroxidation of the iron. The sedentary soils of the South show very plainly also that the second process does not keep pace with the first; for, while the superficial soil exhibits the brilliant colors of the ferric oxides, in the lower portion, which shades off insensibly into the underlying rocks, grayish and bluish tints prevail, indicating that the iron is still chiefly in the ferrous state. Hence the normal vertical order of colors in sedentary detritus seems to be as follows, beginning at the base: 1, Bluish, grayish, and neutral tints, due to ferrous oxide; 2, the yellow and brown tints of the ferric hydrates; and, 3, in warm countries, the red resulting from the dehydration of the ferric hydrates.

The foregoing embodies the chief points of my previous paper, which was based very largely upon personal observations made some twenty years ago while I was engaged in mining operations in North Carolina and Virginia, and enjoyed unusually favorable opportunities for observing fresh and normal sections of the sedentary soil. Later, also, I travelled extensively in these and other Southern States; in the West Indies, from Cuba to Trinidad and the northern coast of South America; and in Europe, from Sicily to Scandinavia — giving particular attention everywhere to the colors of the soils. That paper was pub-

lished in the hope that it would call out the observations and views of other geologists; but it appears to have borne no fruit of that kind until the appearance, a little more than a year ago, of the comprehensive and valuable monograph by I. C. Russell on the "subaërial decay of rocks and origin of the red color of certain formations,"[1] to which the author has appended an important bibliographic list. In the first part of this essay, relating to the subaërial decay of rocks,

> Attention is directed to the widespread decay of the surface rocks throughout the Appalachian region, south of the southern limit of the glaciated area of Northeastern America. It is shown, also, that rock-decay is far more advanced in the Southern than in the Central and Northern Atlantic States, and increases gradually southward. This variation is thought to be due to climatic causes, combined with recent orographic movements which have accelerated denudation in the northern portion of the region under discussion. From a brief review of the geographical distribution of residual deposits in various regions, together with other considerations, the conclusion is drawn that rocks decay most rapidly in warm, humid climates.

After describing the characteristics of the residual or sedentary clays of the South, including the color, Mr. Russell refers to my contribution as follows:

> The contrast in color between northern and southern landscapes in the Appalachian Belt has recently been explained by W. O. Crosby . . . on the assumption that the observed difference of color has resulted directly from differences of temperature between the North and South. In the essay referred to it is urged that the higher temperature at the South is capable of dehydrating the ferric oxides impregnating the soils, thus changing their color from yellow to red; and also that the red color of residual clays is a superficial phenomenon, confined to the immediate surface of the deposits. My own observations do not confirm these conclusions. At many localities in the Appalachian region south of Pennsylvania where residual deposits were observed, the characteristic red color was seen to extend far below the surface, and as a rule to reach the bottom of fresh exposures. In many localities the color of the residual clays at a depth of twenty or even fifty feet is similar, so far as the eye can distinguish, to the color in the same sections only a foot or two below the surface. The great depth to which the red color extends renders it evident that it cannot be directly dependent on solar heat. Again, over considerable areas in the South the surface clays are various shades of yellow, which would not be expected if the red color of adjacent fields is due to temperature.

During the last six years I have gradually come to attach less weight than at first to the difference in temperature as a sole and sufficient cause of the difference in color between Northern and Southern soils; but I still hold that it is an important factor in the entirely adequate explanation; and so, apparently, does Mr. Russell. In fact, he proves that the cause must be largely climatic by showing: (1) that

[1] Bulletin No. 52 of the United States Geological Survey, Washington, 1889.

the typical residual clays of the South are usually red, and common to a great variety of geological formations; and (2) that, as already quoted, they are conditioned in a very large degree by the combined action of heat and moisture, being but scantily developed in the arid regions of the South, and never with a red color under the humid climate of the North. Since the rocks from which the red clays are derived are almost never red, the redness is evidently incidental to the kaolinization, and its cause may therefore be looked for with much probability, at least, among the conditions favoring kaolinization, of which heat is clearly one of the most important. Again, in spite of the recent glaciation, evidences of kaolinization are not wanting in the North; but the resulting clay, the true sedentary soil of the North, is never red, indicating very plainly that, while a warm climate is not strictly essential to the formation of residual clays, it is a necessary condition of the development of the red color. Prof. J. D. Dana emphasizes this point in a review[1] of Mr. Russell's work, from which a few sentences may be quoted:

> The contrast in colors between the Northern and Southern States is spoken of (by Russell) as "a contrast between a glaciated country and a region in which atmospheric decay has progressed uninterruptedly for ages." Mr. Russell, knowing less of New England than of other parts of the country, does not appreciate as strongly as Professor Crosby, whom he criticises, the full character of this difference. There is wide decomposition at the North, and its rapid progress in the case of syenites, mica schists, gneisses, granites, and hornblende schists, during the past forty years, is very strikingly exhibited alongside of many railroad cuts. The fact to be accounted for is that these decompositions over New England, whether in the trap of trap dikes or in metamorphic rocks, produces almost *never* red earth; while at the South, red earth predominates. The glacial movements and orographic changes have nothing to do with this. The fact is simply that in New England the result of the iron oxidation attending the decay is limonite, the hydrous, yellow-brown iron oxide, and not anhydrous Fe_2O_3. The writer has often tried to discover a reason for the different result at the South; he does not find one in Mr. Russell's excellent paper.

In what manner, if any, the milder climate of the South promotes the development of the red color, except directly by favoring the dehydration of the iron oxide, I have not attempted to explain; but when we consider that, aside from the glaciation of the North, there is virtually or primarily but this one physical contrast between the North and South, it seems impossible to doubt the existence, directly or indirectly, of a causal connection between the temperature and the color of the soil. The fact that Mr. Russell questions this conclusion caused me, however, less surprise than his attempt to fortify that negative position

[1] American Journal of Science, Volume XXXIX, 1890, pp. 317–319.

by denying that the red color of Southern clays is essentially a superficial feature. I was amazed at his statements in this regard, and asked myself again and again if my recollection of what I had seen in the gold mines of North Carolina and elsewhere could possibly be so far astray. Being unwilling to controvert the views of so competent an observer without a fresh examination of the facts, I have waited for an opportunity to go over the ground again. Fortunately, I have been able during the past year to make two journeys in the South — one to Asheville, by the usual route through the Piedmont district of Virginia and North Carolina, and the other down the great Appalachian Valley to the vicinity of the Natural Bridge — giving, in both cases, especial attention to the distribution of the colors in the superficial detritus.

Briefly stated, the general result of these recent observations is a complete confirmation of my original views; but I am able now to make more definite statements than formerly. In the great majority of the sections observed in the Piedmont region of both North Carolina and Virgina, including all which could be described as normal examples, *i. e.*, as unmodified by disturbance or erosion, the distinctly red soil is very superficial, varying in thickness, as a rule, only from two to five feet, and very rarely exceeding ten feet. It is usually reddest at, or near, the surface, changing downward gradually, more rarely abruptly, through various shades of orange to yellow; while occasional complete sections show the yellow changing through paler tints to gray or the color of the underlying hard rocks. This is certainly the normal succession of colors in a complete vertical section, as described in my earlier paper. The slight depth — two to five or ten feet — reached by the red color was noted again and again in scores of sections. It was usually easy to see, however, how hasty or unguarded observations might lead to a different conclusion; for the wash of the rains has, in most cases, carried the superficial red clay down over the entire face of the section. In this way the orange and yellow are often almost completely blotted out, except where an occasional gully, one to several feet in depth, notches the face of the cutting and exposes a clean, fresh, undisturbed, vertical section of the clays. When passing through the railway cuttings my eyes were always focussed upon these gullies or miniature ravines; and when on foot I have proved by actual digging that the yellow color seen in the middle and lower part of the gullies is strictly *in situ*, and that the red color at the same levels

between the gullies is what it appears to be, a mere surface wash —a red veil descending from the red crown at the top of the section.

For the past twelve years I have had in my teaching collection a series of specimens illustrating the normal gradation of colors from the surface soil to the underlying rock, which were carefully selected for this purpose at a gold mine in Fluvanna County, Virginia; the entire section, from the surface to the unaltered mica schist, measuring, in this instance, less than 12 feet, and the red clay less than 3 feet. More recently, I have collected a similar series in the vicinity of Rock Creek, in the District of Columbia.

In connection with his criticism of my views, Mr. Russell refers to a quotation, on an earlier page of his essay, from an account by Prof. E. A. Smith of the residual clays of Alabama.[1] Professor Smith's description, so far as it is pertinent to the present discussion, is as follows:

> The soil of the red lands is derived from the decomposed hornblendic gneisses and slates, which in many places, where exposed in washes or gullies, are seen to be mere stratified clays, containing fragments, more or less angular, of the quartz veins or seams, which are nearly always interbedded with the other rocks of this region. The top stratum of this soil, from two to three inches in depth, has often a dark chocolate-brown color, but below it becomes a bright red, and at varying depths, from ten to fifteen feet, becomes a *yellowish, hard clay. Where the freshly decomposed rocks are seen the color is yellowish rather than red, the latter color (red) being darker and more intense, apparently, the further removed the soil is from its original position* and the more it is affected by the decay of the vegetable matter.

The italics are my own; but how this description lends any support to Mr. Russell's criticism is certainly not very clear; on the contrary, it corroborates my statements that the red color is limited to the vicinity of the surface, and that the deeper and newer clay in every normal section is yellow. Professor Smith's description (which would apply equally well to large areas in Georgia) indicates, what might naturally be expected from the lower latitude, a greater average thickness of the red clay than I have observed in North Carolina and Virginia.

Whatever the cause of the superficial dehydration of the ferric oxide, changing the color from yellow to red, it is unquestionably a slow process; and since the red portion of the soil is clearly the oldest part, residual, unlike sedimentary, deposits growing from the top downward, we may find here an easy and sufficient explanation of the point

[1] Geological Survey of Alabama, Report for 1881 and 1882, p. 184.

in Mr. Russell's criticism to the effect that "over considerable areas in the South the surface clays are various shades of yellow, which would not be expected if the red color of adjacent fields is due to temperature" (page 42). We have only to suppose that erosion, which acts upon all areas in some degree, is here sufficiently rapid to prevent the development of the red color, removing the clay before it has time to change its hue. Mr. Russell has pointed out very clearly that the simple existence of the residual clays proves a general predominance of decay over denudation; but even where the rate of decay is uniform, the ever varying conditions of erosion must give rise to every phase between the greatest observed depth of undisturbed residual clay with the full complement of colors — red, orange, yellow, and gray — and the hard, bare ledges seen in crags and stream beds; and we may safely predict that in passing from the one extreme of denudation to the other, these tints will, as a rule, appear in succession at the surface.

According to my observations, the surface of the strictly sedentary detritus of the Piedmont region is rarely yellow, except where the conditions are obviously more favorable for rapid erosion than over adjacent red areas. Often in the same limited field it can be seen that the steeper slopes of the land, or, in general, those areas most exposed to the wash of the rains, are yellow, while the more level or less exposed parts are red. The colors thus tend to distinguish the areas of slow and rapid erosion; but it is intended, of course, to embrace in the latter, as in the former, only the general ablation of the surface, and not the gullies so characteristic of Southern hillsides, which, when once started, quickly cut clean, vertical sections through the clays. Now the fact that the red clay washed by the rains from the steeper slopes must be spread, in large part, over the more level areas immediately adjoining, affords an obvious and simple explanation, not only of the constantly varying thickness of the red clay, but especially of the exceptionally great thicknesses sometimes observed. I have purposely neglected to take account of these before, because the statement that the red clay is mainly superficial was intended to apply only to detritus that is still *in situ*, or strictly sedentary. No argument is required to show that by rain-wash from surrounding slopes the red clay might be accumulated upon a limited area to almost any depth, even fifty feet, as stated by Russell. But it is an obvious mistake to

compare such special accumulations of transported detritus, which are in general readily recognized by their situations and horizontal stratification, with clay which is still *in situ*. The same principle also explains the exposure of yellow clay over level areas; for evidently when the red clay has been completely washed from the slopes, the yellow clay will experience a similar ablation; and it is not difficult to see how the conditions would often be favorable to a commingling or interstratification of red and yellow clays.

On passing from the Piedmont district of North Carolina to the Blue Ridge and the table-land beyond, the red clay, through the accelerated erosion, rapidly disappears, except in the most protected places. The outcropping ledges and crags are bordered by successive and perfectly blended zones of disintegrating rock, and gray, grayish yellow, and yellow clays; and only, as a rule, on the gentlest declivities are orange and red tints observed. The same conditions were observed in the Appalachian Valley, between the Pennsylvania line and the Natural Bridge, yellow and orange being the prevailing colors, and red rarely occurring in considerable patches. Although the comparative absence of the red clay in these more elevated and mountainous areas might be attributed to the colder climate, the correlation with the accelerated erosion appears on the whole more simple and direct; and the latter must certainly be regarded as at least the chief cause.

Although it appears unnecessary to materially modify my previous statements concerning the distribution of the colors in sedentary detritus, I am, as already stated, less disposed than formerly to insist upon the entire adequacy of the warmer climate of the South as an explanation of the red surface soil of that section.

The dehydration of the ferric oxide is not wholly dependent upon heat or pressure or any obvious extraneous agency, but it is in a large degree, apparently, a spontaneous process. Of this we have abundant evidence in nature and in the laboratory. When the iron, which exists in the various silicate minerals chiefly in the ferrous state, is liberated and peroxidized during the decay of these species, it combines naturally with a very large and indefinite proportion of water, forming the yellow hydrate which is seen as a flocculent or a gelatinous colloid in the waters of springs, bogs, and marshes, and when the hydrate is obtained as a precipitate in the laboratory. But this colloid mass, even if immersed in water and entirely undisturbed, gradually and spontaneously

gives off a large part of the water which the ferric oxide has so greedily absorbed when in the nascent state; and it appears thus, as it slowly solidifies and hardens, to pass in succession through the forms of the various native yellow hydrates — limnite, xanthosiderite, and limonite, to göthite. That this progressive change continues is evident from the fact that these yellow hydrates are gradually replaced in the older formations by the red hydrate (turgite) and by ferric anhydride (hematite). When occurring as original or contemporaneous, and not as secondary, deposits, the yellow ores of iron are found, as a rule, only in the later rocks; while the red ores are very generally restricted to the earlier rocks. This genetic relation of the yellow and red ores is one of the most familiar and generally accepted facts in geology. However recent the origin of the red ore (turgite or hematite) may appear to be in any case, we naturally infer that it was first yellow, and that it has passed slowly or rapidly, as the case may be, but gradually, through the series of yellow hydrates.

The frequent absence of any apparent cause for this change leads us to assume that it is essentially spontaneous, in the sense that, although often hastened by heat or other extraneous agency, it would take place eventually without such aid. This view is strengthened by the analogous series of changes exhibited by silica. The gelatinous silicic hydrate obtained in the laboratory or seen in the waters of thermal springs, loses water and hardens spontaneously, and eventually reaches the comparatively stable condition of opal, which is comparable with limonite; and since opal, like limonite, is always of recent origin, we know that it must change more slowly into anhydrous silica or quartz, as limonite changes to hematite. The aluminum and other hydrates manifest a similar tendency. As the dehydration continues, there is a concomitant change from the amorphous to the crystalline state, analogous to that observed in the devitrification of glass and obsidian; and the dehydration is probably as spontaneous as the crystallization.

If it be conceded that the dehydration is virtually, if not absolutely, spontaneous, and there is no apparent alternative, it follows that the color of a deposit, so far as it is due to ferric oxide, is, other things being equal, a function of its geological age. In other words, the color naturally tends with the lapse of time to change from yellow to red; and, although this tendency exists independently of the temperature,

it is undoubtedly greatly favored by a warm climate. Applying this principle to the sedentary soil of the South, we find that the superficial portion is red, not alone because it is exposed to a higher temperature than the subjacent yellow clay, but also because it is the oldest part. On the other hand, the limited occurrences of post-glacial sedentary detritus in the North are, in the absence of the favoring climatic influence, still too young to exhibit the change of color even superficially.

It is generally conceded that the glaciated area was, in preglacial times, covered with a continuous sheet of sedentary detritus similar to that of the South, but probably not so thick. This now forms a large part of the till or bowlder-clay; and in its colors, thoroughly mixed and greatly diluted with gray (triturated rock), we have the color of the till. A simple experiment shows that a small proportion of the red clay of the South mixed with gray clay gives a decided reddish tinge to the whole. The absence of this reddish tinge in the till may, however, be at least partly explained by the strong erosion attending the preglacial elevation of the land; on the same principle that the red clay is now mainly wanting on the mountains of the South. It seems, however, impossible that a thickness of red clay in the North comparable with what now exists in the South could have been so completely swept away or extinguished as the character of the till would indicate. Hence we naturally fall back again upon the alternative view that the red color was developed very scantily, if at all, in the North, in preglacial times, and that, after all, the climatic difference is an important factor in the true explanation of the contrast in color between the residual clays of the North and South. Certainly no other explanation accounts so satisfactorily for the fact that in low latitudes flows of basaltic lava assume in a few years a bright red color, which never happens in the North. The general conclusion, then, to which the foregoing considerations lead is that the color-contrast is due chiefly to the difference in climate, but that the operation of this principle is modified in a general way by the essentially spontaneous tendency of the color to change from yellow to red.

IRRIGATION IN ARIZONA.[1]

By F. H. NEWELL.

THE total area in Arizona on which crops were raised by irrigation in the census year ending June 30, 1890, was 65,821 acres, or 102.8 square miles, less than one tenth of one per cent of the entire area of the Territory. The aggregate number of farms was 1,448, and of these, 1,075, or 74%, depended upon irrigation, the remaining 26% being stock ranches, or farms situated high in the mountains, where crops can be raised by what is known as "dry farming." The average size of irrigated farms, or rather of the irrigated portions of farms on which irrigation was practiced, was sixty-one acres. In this connection the term "irrigated farm" is used to include only the area on which crops were raised by irrigation, the uncultivated portions of such farms not being taken into account. With this understanding, the irrigated farms or areas cultivated by each person have been classified as follows: seven irrigated farms of 640 acres or upwards, 15 of from 320 to 640 acres, and 57 of from 160 to 320 acres. These 79 farms contain an average of 287 acres each, and have a total area of 22,656 acres, or 34% of the entire amount watered in the Territory. The remaining 996 farms, under 160 acres in size, comprise only 66% of the total irrigated area, and average 43 acres each. In other words, 7% of the farmers of the Territory owned over one third of the productive land, and the remaining 93% of irrigators owned an average of 43 acres each.

[1] Census Bulletin No. 35, Feb. 27, 1891.

COUNTIES.	Number of irrigators.	Total irrigated acreage in crop.	Average size of irrigated farms, in acres.	Average value of products per acre.
Total	1,075	65,821	61	$13.92
Apache	182	5,545	30	$13.36
Cochise	52	2,372	46	26.93
Gila	18	815	45	23.85
Graham	199	7,556	38	16.06
Maricopa	327	35,212	108	9.26
Pima	85	3,085	36	30.36
Pinal	115	6,919	60	11.25
Yavapai	91	3,762	41	31.00
Yuma	6	555	93	10.50

Taking all the counties in the Territory, with their varying conditions, the average cost of water right was $7.07 per acre. This includes all cases, from the one extreme, in which the farmer dug his own ditches from the river — the cost of water right in that case being the amount which the ditch cost him in labor and material — to the other extreme, in which he purchased his water right from some company, paying a certain sum per acre for the privilege of renting or buying water each year. The selling value placed upon this by the farmer, whenever his right was transferable, was $12.58. The average annual cost for water was $1.55 per acre, this expenditure being either in labor in keeping the main ditches and dams in repair, or paid as a cash assessment or rental to an association or corporation.

Besides the first cost of the water and the annual assessment for its use, an estimate has been made of the first cost of bringing the land from a wild state under cultivation by irrigation beyond the expense for the water right. This estimate, which is $8.60 per acre, includes the cost of ploughing, grubbing sagebrush, cutting mesquite, fencing, and levelling, or otherwise preparing the ground for irrigation.

Assuming, then, that the original purchase price of the land was $1.25 per acre, the cost of preparing for cultivation by irrigation

$8.60 per acre, and the first cost of water right $7.07 per acre, the land cost the original owners a total of $16.92 per acre. It is ascertained, for comparison with this, that the average valuation, including buildings, fences, and other improvements, of the land on which irrigation is practiced, is placed by the owners at $48.68 per acre, showing an apparent profit, less cost of buildings, of $31.76 per acre.

In comparison with the annual outlay for water it is found that the average annual value of farm products is $13.92 per acre, leaving the farmer $12.37 per acre per annum as a return for his labor and as interest on his investment.

On examination of the figures for the different counties, it will be noticed that in general the value of products per acre increases as the average size of the farm diminishes. For example, in Maricopa County the average size, 108 acres, is the greatest in the Territory, while the average value of product, $9.26 per acre, is the least. Next comes Yuma County, with an average of ninety-three acres per farm and products averaging $10.50 per acre; then Pinal, with an average of sixty acres per farm and products of $11.25 per acre. In other words, the larger irrigated farms were not so closely tilled as were the smaller, and a lower-priced crop was the result.

Deducting the 79 large farms, on which the average value of product was $9.05 per acre, there remain 996 farms, with an average extent of 43 acres each, on which the value of product was placed at $16.75 per acre; that is to say, the farmers, in the main, if their statements are correct, must have supported themselves and made their profits out of gross earnings averaging $720 per annum each.

These results have been computed from data acquired both by field work and correspondence. The enumerators in the several districts obtained the acreage, and likewise the value of land and products of each farm. On the completion of this field work a blank schedule was mailed to each farmer, requesting a more detailed statement as to the location of his land, the source of his water supply, the cost of irrigation, and also as to local customs. The replies were compared with the statements of the enumerators, and in every case of apparent misunderstanding or serious discrepancy a second letter was sent. The information thus obtained was then carefully examined in the light of personal knowledge of the cli-

mate and products of the Territory. Besides the blank schedule sent to farmers, correspondence was entered into with the owners or officers of canals, with a view of obtaining statistics as to cost of construction, etc. The result of this correspondence will be given at a later date.

The agricultural and irrigable land of Arizona is situated in the southwestern half of the Territory. If a line be drawn from the northwestern to the southeastern corner diagonally across the Territory, this line will lie for a greater portion of the distance along the face of the great escarpment which divides the high plateaus from the plains of the Gila basin. Against the face of this escarpment the larger portion of the available moisture is precipitated, rolling back to feed the tributaries of the Gila, thus rendering possible a certain amount of irrigation in the narrow valleys, especially on the Gila and Salt River plains near the point where their waters leave the cañons. High up on the edge of the plateau country and among the mountains, at elevations of from 5,000 to 7,000 feet, a little agriculture is successfully carried on without irrigation, usually in connection with stock raising, or in the immediate vicinity of mining towns. The crops raised, however, are comparatively insignificant.

The acreage at present under irrigation may be regarded as approaching the maximum possible with the present supply of water and methods of using it. In other words, all the easily available water has been utilized, and expansion can come only by a greater economy in the use of the existing supply, or by the adoption of systems of storage for the conservation of the flood water now annually running to waste. The irrigators look forward to the latter alternative as the most effectual means of obtaining relief from present troubles and uncertainties. Progress in this direction will, however, be slow, from the necessity of a large outlay of capital before any return can be realized, and from the fact that the controllers of capital, whether governmental or private, have had comparatively few facts on which to base reliable estimates. The amount of water that can be reserved by storage is known from common observation to be very large, but it is usually greatly overestimated, from the fact that even a small volume of water, coming all at once and with great velocity, is often extremely destructive, and creates a vivid

impression, while the same amount, if distributed through as many days or weeks as it is hours, would not excite comment. Measurements have been made in a few instances by engineers and by the United States Geological Survey; but the operations of the latter were discontinued before a range of much over a year had been obtained. For example, taking what is probably the best storage site in Arizona, that on the Gila at the Buttes above Florence, the mean discharge at this place, as shown in the eleventh annual report of the director of the United States Geological Survey, from September 1, 1889, to August 31, 1890, when operations were suspended, was 503 second-feet, averaging 1,000 acre feet per day, or 365,000 acre feet for the whole year. Assuming a water duty of 100 acres to the second-foot, this, if all the water could be stored, would irrigate 50,000 acres, instead of the 7,000 acres or less now irrigated in the vicinity of Florence. A large reduction from this theoretical amount must, however, be made for losses by evaporation and seepage. Without going into a discussion of the measured water supply, this will suffice to show that it is possible to determine the volume and intensity of floods, and that when this has been done the water-storage problem will be in a fair way to solution, since only then will it be possible to prepare reliable estimates of costs and profits.

Shortage of water, and consequent loss of crops on irrigated land, are reported by the majority of farmers whose rights to water are secondary to those of the first comers. The latter, however, report that there is ample water for all their own needs, except in general from the middle or latter part of June, through July, August, and into September. Before this time, however, the cereals, with the exception of corn, should be matured, and probably two or more cuttings of alfalfa made.

For the greater part of the Territory it may be said that irrigation is practiced or is necessary to successful farming throughout the entire year. In the lower plains the temperature is such that crops will grow and mature at any season of the year, provided there is a sufficient supply of moisture. Crop follows crop in constant succession, if only there is an abundance of water in the ditch, or of summer rains. During the winter, and also in the early spring and late fall, water is used on the alfalfa and hay crops, from three to six cuttings of alfalfa being made annually, the average of the

entire Territory being five. Usually two waterings are given for each cutting, the total amount of water used being thus largely in excess of that required by any other crop. Later in the spring, when the rivers begin to decline, the alfalfa is neglected, all the water being needed for the cereals and vegetables, and still later, before the summer floods set in, in many places the entire flow has to be taken to save the trees and vines.

The water is in most cases applied by flooding — as, for instance, on alfalfa and grain — or through furrows laid off at regular intervals, no especial care being taken in the preparation of the fields. The Mexicans still practice the old method of flooding in small "pools" or rectangular areas, separated by ridges of earth. The farmers, almost without exception, look forward to better methods of distributing and applying water. Since the soil and local conditions vary so widely, there can be no absolute rule as to the number of waterings or the time required for the different products. There is a growing impression that in many cases too much water is used, and that better crops could be matured by using the water more sparingly, which would also have the effect of increasing the cultivable acreage.

Apache County occupies the extreme northeastern corner of Arizona, and borders upon New Mexico on the east and Utah on the north. The Navajo Indian reservation covers the northern half of the county, and the Atlantic & Pacific Railroad grants cross the southern half, thus leaving comparatively little of this vast area of 21,060 square miles open to settlement under the general land laws. The railroad just mentioned follows the Little Colorado River, and then turns up one of its tributaries, the Rio Puerco. The principal settlements are along this railroad and south of it on the Little Colorado and on Silver Creek, a tributary of this stream.

In these valleys, which are at a general elevation of from 5,000 to 6,000 feet, are long stretches of good agricultural land, which only need water to become very productive. The water supply, however, is limited, and although great quantities run to waste in time of flood, there is generally a deficiency during June and July, so that the acreage now under cultivation does not always receive its full share. There are reported to be good facilities for water storage near the head of several streams. Dry farming is practiced on

about twenty-five farms in the forest belt, and corn, wheat, rye, beans, potatoes, turnips, etc., are raised without irrigation in the vicinity of Show Low, the elevation here being 7,000 feet and upward. In the lower valleys, however, nothing can be grown without the application of water by artificial means.

As shown by the table, the total acreage irrigated is 5,545 acres. From the statements received from the farmers it is doubtful whether in ordinary seasons a larger acreage could be successfully cultivated without the use of stored waters. The principal ditches reported at this time are the East and West Taylor, East and West Snowflake, and the Woodruff, the total cost being $25,000, and the land furnished with water aggregating 2,500 acres. One of the most notable engineering features is the attempt to dam the Little Colorado River by a structure 225 feet long and 30 feet high. This has been washed out and replaced seven times.

The first cost of irrigation is reported to be from $4 to $12 per acre, the average being $7.50, while the average selling value put upon the transferable water rights is quoted at $9.65 per acre. The annual assessment, an expense for maintaining the ditches, varies from 25 cents to $4 per acre, averaging $1.60. Beyond the outlay for water, the general expense of preparing the ground for cultivation is $7.25 per acre, thus making the first cost of irrigating land $14.75 per acre, taking the county throughout.

Cochise County is in the southeastern corner of Arizona, bordering upon Mexico and New Mexico. In altitude it ranges from 3,000 to over 6,000 feet. The northern end of the county is crossed by the Southern Pacific Railroad, from which a branch line runs southward to Tombstone. There are in all 2,372 acres irrigated, the farms being confined almost exclusively to the valley along the San Pedro River. This stream is the main water supply of the county, the little farming that is done at any distance from the river being confined to the mountain valleys, where small springs occur.

There being far more arable land than river water, the latter is in great demand, and in many localities there is constant litigation concerning water rights, so much so that it may be said that the legal expenses are heavier than the cost of constructing ditches. During the periods of low water the entire stream is taken out by dams, some water, however, reappearing in the channel, to be diverted

in turn by a dam below. There are a large number of small private ditches along the San Pedro River, but there is no comprehensive system for utilizing or dividing the water. The lowest stage of water in this river is usually reached in June, when there is the greatest demand, and the rise begins again after the commencement of the summer rains, during which time the flood waters run largely to waste. All the land which the ordinary unregulated flow of the river will supply, and probably more than can be supplied in certain seasons, is now under cultivation, and yet the demand for agricultural products far exceeds the amount that can be raised. The storage problem will, however, have to be settled before any further advance can be made.

It is impossible to raise crops without irrigation, except in a very few localities in the mountain valleys, where, after the rainy season, small crops of corn and potatoes are successful. With irrigation, however, almost all the fruits and other products of the temperate zone are grown, with close cultivation one crop following another with but little loss of time.

Graham County lies to the southeast of Gila, between Apache and Cochise Counties, filling in the eastern side of the Territory. It is thus in or near the head waters of the Gila River, and, like Gila County, is largely mountainous. The principal area of agricultural land is in the Pueblo Valley, extending from a cañon above Solomonsville for about thirty miles to Fort Thomas, the principal settlements being, in order, Solomonsville, Safford, Central, and Pima. The Gila is the source of supply for the valley. A number of dams are placed across it at intervals of two miles or more. When the flow of the stream diminishes in May and June, the dams of logs, brush, and stone are tightened so as to turn all the water into the canals. Below each dam, however, the water begins to rise in the bed of the stream, so that by the time the next dam is reached there is apparently as much water as before. If the summer rains fail, the river may become entirely dry in July and August, and a loss of crops be the result.

At present the acreage under cultivation is not greatly in excess of the usual water supply, and the losses are not such as to call for immediate water conservation. In view of future extensions, however, it is already recognized that active steps must soon be

taken. There appears to be no comprehensive system of water distribution, and the present needs seem to point to a consolidation of the various small ditches into a few high-line canals, both to reduce the expenses and to effect a greater economy in the use of the water. The river, occupying a wide, sandy bed, is unstable, and during freshets is liable to cut new channels, leaving the dams on dry land.

Some cultivation by irrigation is successful in the valleys south of the river at the foot of the mountains, where small streams or springs issue. The greater portion of this water, however, is lost for lack of facilities for holding the spring flow until later in the season.

Gila County is the smallest in area in the Territory. It occupies a position largely within the drainage basin of the Salt River, on the south, crossing the mountains and reaching to the Gila River. On account of its position it is comparatively well watered, but on the other hand the valleys are narrow, and there is little arable land. The White Mountain Indian Reservation covers the greater portion of the county, leaving only a narrow strip of land on the western side. The tilled land is principally along Salt River, between Pinal and Tonto Creeks, or in their vicinity. Among the head waters of Tonto Creek and in the Tonto basin, at an elevation of from 6,000 to 7,000 feet, corn and potatoes are raised without irrigation if the land is carefully tilled. Other crops, however, require the artificial application of water.

Maricopa County leads in agricultural development, as well as in the value and extent of irrigation. Over one half of the irrigated land of the Territory is situated in this county, the amount, however, being small in comparison with the arable land which may in the future be brought under cultivation. The water supply is derived almost entirely from Salt River and from the Gila below the junction with the Salt. A large number of canals take water from both sides of the first-named river, their head works being at irregular intervals from each other, beginning near the Verde and continuing to Gila Bend. Statistics relating to these canals, some of which are among the most notable in the United States, will be given in a future bulletin.

Taking the county as a whole, it may be said that the water supply is ample for the acreage now under cultivation, except during

the latter part of June, and in July and August. Before this time of scarcity occurs, however, all the grain crops, with the exception of corn, should be matured, and probably two cuttings of hay obtained, so that the water can then be used to save the fruit trees and vines. On the older canals and ditches the farmers report that there is sufficient water, but on the newer systems there are many complaints against the exactions of the corporations and the amount of water and time allotted to each irrigator.

The need of better canal systems, of greater economy in the use of water, and especially of the storage of flood waters, is insisted upon by all irrigators. The enormous extent of good arable land and the volume of water going to waste every year seem to have impressed every resident of this county, and there is a unanimously expressed hope that either the national government or capitalists will in the near future begin the construction of reservoirs at one or more of the many favorable points. Storage in a small way has already been tried, and is reported to be successful.

Most of the existing dams and other contrivances for diverting water from the river to the smaller ditches are of such a temporary character as frequently to be partially or even wholly destroyed by floods, resulting in large expenditures of time and labor and in loss of crops. The ditches are all open, and their beds and banks are not lined, great loss by evaporation and seepage thereby necessarily occurring in so warm and dry a climate.

The inhabitants are enthusiastic as to the productiveness of the soil, and report that all the crops and fruits of temperate and semi-tropical zones flourish and attain a wonderful growth and perfection. The altitude varies from 500 to 2,000 feet, and the temperature is sufficiently high to insure the successful cultivation of cotton, sugar cane, and other Southern products.

Taking the county as a whole, the cost of water is $5.75 per acre, and the present value of this water right when transferable is quoted at $10.87 per acre, while the estimated cost of bringing the land under cultivation beyond the above expense is $6.45 per acre, making a total of $12.20 for the average outlay required beyond the purchase price of the land before a crop can be raised. The annual assessment or cost of cleaning and repairing ditches is estimated at $1.12.

The average size of irrigated farms in this county is 108 acres. Dividing them into two classes, those of 160 acres and upward and those under 160 acres, it is found that there are 64 farms of the first class, averaging 296 acres each, and 263 farms of the second class, averaging 62 acres each.

Mohave County occupies the extreme northwestern corner of the Territory. There is as yet no cultivation reported, cattle raising being the only agricultural industry.

Pima County is situated along the central part of the extreme southern border of the Territory, adjoining Mexico. Agriculture is confined to the eastern end, near Cochise County, where the elevations range from 2,500 feet upward. The Santa Cruz and Sonoita and their tributaries are the only sources of water supply, with the exception of a few springs among the foot-hills of the mountains. The amount of water is small in comparison to the acreage already under cultivation, and crops are frequently lost during the dry season.

Pinal County stands second in importance in regard to agricultural products. It lies between Maricopa and Pima Counties, and includes the most favorable portion of the Gila Valley; that is, the portion adjoining the foot-hills and cañons from which the river issues. The agricultural land is in the centre of the county, around and near Florence, with the exception of a small amount in the San Pedro Valley near Dudleyville.

The necessity of water storage is keenly felt in this county, from the scarcity experienced during a great part of the year. There are excellent opportunities for holding all the flood waters, and surveys have demonstrated the feasibility of the project, the only apparent obstacles being the lack of capital and of favorable legislation concerning the control of the water. The quantity of water in the Gila is reported to be decreasing on account of the large and increasing number of diversions on the upper portion of the stream, in Graham County.

The average cost of a water right is $6.94 per acre, and of clearing and bringing the land under cultivation, $11.50, making a total of $18.44 per acre. The annual cost per acre for water is estimated at $1.81.

Yavapai County, while the largest in area, being one fourth that of the entire Territory, contains relatively the smallest proportion of

irrigable land. This county lies in the northern half of Arizona, adjoining Utah on the north, and contains the greater portion of the grand cañons of the Colorado. These stupendous gorges, the most wonderful in the world, cut the great plateau to the depth of from 3,000 to 6,000 feet. The minor lateral cañons, in which flow the tributaries of the Colorado, are also cut to a great depth, which decreases toward their head waters. Thus the water of the northern part of the Territory, though large in amount, is wholly useless, lying as it does hundreds and thousands of feet below the level of the arable lands. It is only toward the southern portion of the county, where the great plateau begins to break off and the valleys are less deep and narrow, that agriculture has been seriously attempted. Along the line of the Atlantic and Pacific Railroad, which crosses the county from east to west at an elevation of from 5,000 to 7,000 feet, some crops, especially for forage, are raised without irrigation. For example, at Flagstaff, at an elevation of about 7,000 feet, corn, potatoes, and vegetables, as well as a little wheat, oats, and barley, are thus cultivated, the cereals being generally cut for forage purposes. The same is true of Prescott, although near that place irrigation is employed wherever practicable. On the head waters of the Agua Fria, at an elevation of about 4,500 feet, there is also a little dry farming.

The principal bodies of irrigated lands are on the Verde and its tributaries, Oak, Clear, and Beaver Creeks, above and below Camp Verde, where a large number of small ditches are owned by private individuals. On Walnut Creek, which heads west of Prescott and flows northward into Big Chino valley, and on Granite Creek to the east, the available waters are all utilized, and there is already need for the storage of the waste waters of the floods. The valleys generally are narrow and shut in by steep walls, and the present agricultural land lies in long, narrow strips, thus obviating the necessity for large canals. The best lands lie high above the water, and can only be reached, if at all, by expensive dams and headworks.

Yuma County, in the southwestern corner of Arizona, comprises the lowest lands of the Territory, and the drainage is consequently in that direction. The extreme lower border of the county is reported as possessing an almost tropical climate. The Colorado River forms the boundary between this county and California on the west, and

is navigable, small steamers running the entire length of that side of the county. There is a large amount of arable land lying along the river, but it is doubtful if dams can ever be placed in this great stream to raise its waters into canals. It is, however, not improbable that considerable land above the flood plains can be irrigated by means of steam pumps. In this climate, where fruits of the choicest and most profitable varieties can be raised, the profits will undoubtedly warrant this method of utilizing a portion of the water.

The Gila River flows across the southern end of this county, but, owing to the large number of canals deriving their water supply from this river in Maricopa County, there is comparatively little water remaining. A number of projects have, however, been started, and in a few years there will probably be a large acreage under cultivation along this portion of the river, although the amount now under cultivation is extremely limited.

ON THE DETERMINATION OF SOLIDS IN WATER.

By ALLEN HAZEN.

A LARGE number of experiments have been made during the last three years at the Lawrence Experiment Station with the use of sodium carbonate in making solid determinations, in the endeavor to make the loss on ignition show with some degree of accuracy the total amount of organic matter present in waters. While the attempts have not been entirely without success, the reduction of nitrate by the organic matter present, and the decomposition of magnesium carbonate, even at comparatively low temperatures, increased the loss, in the case of ground water and effluents, to a considerable extent. In surface waters with comparatively little mineral matter in solution, the sources of error from the above mentioned causes are very slight.[1]

The easier and more accurate determination of albuminoid ammonia and oxygen consumed from permanganate answered our purpose so much better that the determination of loss on ignition was finally abandoned.

It was shown by our experiments that the total solids obtained with the use of sodium carbonate, after deducting the weight of the soda used, is an accurate measure of the solid matter present — far more reliable than the simple residue of evaporation without soda.

If a solution of magnesium chloride is evaporated without soda, as in the usual course of water analysis, there is more or less hydrochloric acid lost, and the residue contains a large and variable amount of water of crystallization; so that the weight of the residue depends very largely upon the manipulation, and it would probably be impossible to proceed in such a way as to make the result correspond accurately with the amount of salt taken in every case. If,

[1] See paper on the Loss on Ignition in Water Analysis, by T. M. Drown, Technology Quarterly, December, 1888; Chemical News v. 59, p. 272.

however, an excess of sodium carbonate is added before evaporation, the magnesia is precipitated as carbonate, while the chlorine remains in solution as sodium chloride with the excess of soda. On evaporation to dryness there is not a trace of hydrochloric acid lost, and the residue contains no water of crystallization and is not deliquescent. Its weight is practically constant under widely differing conditions of manipulation, and, after deducting the weight of the soda used, represents accurately the weight of the anhydrous magnesium chloride originally present; for, in the double decomposition there is no change of weight.

The same can be said of all magnesium salts, and with calcium salts the results are even more exact, owing to the greater stability of calcium carbonate and the ease with which it is dried at 100°.

That this is practically the case is shown by the table which follows on the next page, of results with solutions of various salts evaporated to drynesss at 110°, and, after weighing, igniting in a radiator.

A sample of water, rich in salts but with little organic matter gave the following results:

	Without Soda.	With Soda.
Total solids	30.5	25.1
Loss on ignition	8.3	0.7
Fixed residue	22.2	24.4

Without soda the total solids are too high, on account of water of crystallization, and the fixed residue is too low, because a large part of the chlorine and nitric acid combined with the magnesia were lost on ignition. With soda, the total solids may be taken as an accurate measure of the solid matters present.

LAWRENCE EXPERIMENT STATION,
Massachusetts State Board of Health.

TABLE SHOWING THE RESIDUE OF EVAPORATION OF SOLUTIONS OF VARIOUS SALTS, WITH AND WITHOUT SODIUM CARBONATE.

SALTS TAKEN.	Amount Taken. Grams.	Total Solids.	Loss on Ignition.	Fixed Residue.
Distilled water	100	.0001	.0000	.0001
Distilled water with sodium carbonate, after deducting the amount added	100	.0004	.0000	.0004
Sodium carbonate	.0133	.0135	.0002	.0133
Sodium carbonate	.0265	.0270	.0000	.0270
Sodium chloride	.0250	.0248	.0000	.0248
Sodium nitrate	.0212	.0220	.0001	.0219
Sodium nitrate with sodium carbonate	.0212	.0217	.0001	.0216
Potassium sulphate	.0100	.0102	.0000	.0102
Potassium sulphate	.0250	.0250	.0000	.0250
Potassium sulphate with sodium carbonate	.0100	.0118	.0010	.0108
Potassium sulphate with sodium carbonate	.0250	.0266	.0006	.0260
Potassium nitrate	.0072	.0076	.0000	.0076
Potassium nitrate	.0200	.0204	.0003	.0201
Potassium nitrate	.0200	.0200	.0002	.0198
Potassium nitrate with sodium carbonate	.0072	.0071	.0003	.0068
Potassium nitrate with sodium carbonate	.0200	.0214	.0009	.0205
Potassium nitrate with sodium carbonate	.0200	.0209	.0005	.0204
Calcium chloride	.0101	.0134	–	.0146
Calcium chloride with sodium carbonate	.0101	.0103	.0000	.0103
Calcium chloride with sodium carbonate	.0338	.0347	.0003	.0344
Calcium chloride with sodium carbonate	.0338	.0340	.0003	.0337
Calcium carbonate dissolved in CO_2 water	.0480	.0492	.0003	.0489
Magnesium chloride	.0200	.0390	.0290	.0100
Magnesium chloride	.0200	.0362	.0262	.0100
Magnesium chloride	.0400	.0742	.0540	.0202
Magnesium chloride with sodium carbonate,	.0200	.0211	.0058	.0153
Magnesium chloride with sodium carbonate,	.0200	.0209	.0036	.0173
Magnesium chloride with sodium carbonate,	.0400	.0392	.0066	.0326
Magnesium chloride with sodium carbonate,	.0400	.0435	.0053	.0382
Magnesium carbonate in CO_2 water	.0113	.0136	.0052	.0084
Magnesium carbonate in CO_2 water	.0188	.0219	.0058	.0161
Magnesium carbonate in CO_2 water	.0376	.0427	.0156	.0271
Magnesium carbonate with sodium carbonate,	.0188	.0220	.0059	.0161
Sugar	.0050	.0065	.0050	.0015
Sugar with sodium carbonate	.0050	.0067	.0049	.0018
Sugar with .0212 gr. sodium nitrate	.0050	.0267	.0070	.0197
Sugar with .0212 gr. nitrate, and sodium carbonate	.0050	.0286	.0092	.0196

THE BEGINNINGS OF SCIENCE.

By GARY N. CALKINS, S. B.

In order to gain an outline of the history of scientific thought, a true comprehension of the spirit of the different times is necessary — of that spirit which inspired the great men of different ages to give us their immortal works.

It will be found that there is a cause for all things, and that all are interdependent. Thus the motive cause of the invention of trigonometry was the need of it for astronomical work, and this need was felt because of the desire of the Greek mind to know. But it is obviously impossible to seek the ultimate causes of all changes, and especially so in the time of the beginning of intellectual activity, when authentic history and mythology were so inextricably interwoven that all is obscure.

The development of the true scientific idea began among the most ancient of historic peoples. It is a period when man knew facts well enough for practical purposes, but did not understand the laws which govern them. As with art, science was at first used exclusively for religion. Mr. Herbert Spencer, in his "Genesis of Science," says: "This fact — that in very early stages of social progress it is known that the moon goes through her changes in about thirty days, and that in about twelve moons the seasons return — this fact that chronological astronomy assumes a certain scientific form even before geometry does — while it is partly due to the circumstance that the astronomical divisions, day, month, and year, are already made for us, is partly due to the further circumstance that agricultural and other operations were at first regulated astronomically, and that from the supposed divine nature of the heavenly bodies their motions determined the periodical religious festivals. As instances of the one we have the observations of the Egyptians that the rising of the Nile corresponded with the heliacal rising of Sirius; the directions given by Hesiod for reaping and ploughing,

according to the position of the Pleiades, and his maxim that 'fifty days after the turning of the sun is a seasonable time for beginning a voyage.' As instances of the other, we have the naming of the days after the sun, moon, and planets; the early attempts among Eastern nations to regulate the calendar so that the gods might not be offended by the displacement of their sacrifices; and the fixing of the great annual festival of the Peruvians by the position of the sun. In all which facts we see that, at first, science was simply an appliance of religion and industry."[1]

Under these conditions science could not rise to any great height; we see it bound down to the practical arts required by religion; but later an advance was made, when science, though still only for religion, rose from the practical side to the theoretical, as we see it in the philosophy of the Greeks. The next step was the development of science apart from religion, but, as before, it was first used for practical purposes only. Scientific facts were investigated, not for the love of science, but for their practical value. From this point we find men growing independent in their ideas, and with this independence, freedom in scientific thought. But today it is for the love of truth that men investigate Nature and her phenomena, and with this we have pure science.

We thus follow science in its development from pure sensation to the modern and highest form. At first, mere facts, gained by the impressions of the senses, were used for religious purposes; an advance was made when, though still for religious purposes, facts derived from the senses gave place to theoretical or abstract reasoning. Later religion and science were entirely separated, and science was cultivated solely for its practical value; but the highest point of its development is pure science, cultivated simply for the love of truth.

No one of these periods stands out by itself. All are bound securely together by that law of development which works constantly for the ultimate good of mankind and civilization. At the time when one spirit is shown by the greatest minds of the age, a lower spirit is shown by the lesser lights. When these latter have attained to the position of the former, the great minds are well into the next period of higher development. Thus today we see many people,

[1] "Illustrations of Universal Progress," page 165.

perhaps even the majority, cultivating science solely for its practical value; but for the greatest men of every age it is for the discovery of truth alone.

We have given as the first application of the scientific idea, the use which the most ancient people made of observed facts. But the spirit of observation and the distinction of like and unlike must have come earlier than this in order that these facts should be known to them. In fact, we may say with Lewes: " . . . the dawn of science is coëval with the dawn of human intelligence." Again: "Introduced to this mysterious universe naked and helpless, man is early forced to gain some understanding of its relations to him. At first all is dim sensation. To this succeeds a slowly organized classification of elementary experiences. The great forces of Nature are everywhere at work, everywhere manifesting themselves in manifold and intermingling motions, which he must appreciate, and intellectually disentangle, as far as they directly concern him. . . . At first, man stands before the 'roaring loom of time' gazing in helpless perplexity at the movements of the infinite shuttles, ignorant of the movements which may be beneficent and of those which may be destructive to him. But he cannot remain thus. His necessities soon change this attitude of wonder into an attitude of inquiry." His bodily comfort is of primary importance; hence facts relating to man's physical nature are first ascertained. Then comes a desire for explanation, and thus an intellectual need springs up. He begins to question, and makes out a scheme, plausible to him, by which phenomena are bound together. He knows nothing but by his own feelings, so can explain only by the teachings of his senses, and explains what he sees and hears by what he feels and does.

From the store of knowledge, philosophy arose; meagre at first, but later giving rise to the grandest flights of the human imagination. The actively developing intellect, however, was not to be satisfied with an interpretation of extrinsic phenomena by intrinsic emotions. As the powers of observation improved, it was seen that phenomena agreed less and less with their former explanations. Doubts arose, and with these came a rearrangement of ideas, as well as an increase to the store of facts. These doubts mark the beginning of the first step in the development of science, whereby the practical application of facts gave place to theory.

In the history of human thought there have been two great methods of explaining natural phenomena. That which invariably comes first is known as the subjective method, and obtains today among the uncivilized races of the world. By it the savage is unable to get beyond himself in his explanations. To him the darkness of the night, the gloomy eclipse, the raging pestilence, and all phenomena which are not observed in the regular course of Nature, are the expressions of emotions similar to those which sway him. In other words, he explains Nature through himself.

By the second or objective method, man loses sight of himself and his emotions, and explains the causes of phenomena as inherent in the things themselves. A savage hears the ticking of a watch and sees the motion of the hands; these he can explain only by imagining the chronometer alive. But the owner of the watch knows the laws of force in coiled springs, and the action of cogged wheels, and, by this knowledge, he explains the ticking and the motion of the hands, and thereby shows the superiority of the objective over the subjective method. The old Nature worshippers saw in the sun, a warrior; in the moon, a huntress; and explained the lightning flash as a representation of some god's wrath. They saw in the wind one of the slaves of a god. In the beams of light shining through a rift in the clouds, they saw the sun, a god, drawing up water. Poseidon, the sea god, induces the winds to toss about the frail bark of Odysseus, until Ino comes to the latter's rescue and bids him strip and swim to the shore.

In this we see the homely, every-day life of a people who cannot get beyond themselves in their explanations of natural phenomena. How natural it is for man in this primitive stage to ascribe to a violent storm the same impulse that moves a man to strike his neighbor, when the latter has angered him. They do not conceive that force can originate in anything, except through some anthropomorphic agency. They see phenomena, and can explain them only by their daily habits and usages. "In this subjective method man claims direct knowledge of the nature of things and of the causes of all changes." (Lewes.)

In direct contrast to this is the objective or modern method. Fetiches were no longer consulted for the purpose of making fires, when the savage learned that dry wood will always burn without

their aid. Here the savage has entered into the objective method. "The objective method, by looking *at* things, assuming the position of simple spectator, renounces all hope of ever penetrating the mysteries of existence, of ever knowing the intimate essence of things, and only hopes to detect the invariable order of coexistence and succession." (Lewes.)

To the ancients, who thought the sun a chariot of fire driven across the heavens by a god, our modern ideas of gravity and the relative fixity of the sun would be as incomprehensible as the natural laws, which we know to govern the motions of the planets, are to us. While these laws bring us no nearer to the spirit which regulates the universe, they do have the merit of bringing celestial and terrestrial phenomena into general harmony, and of admitting of a systematic unification of all observed facts. Besides this scientific value, such forms of knowledge remove all traces of superstition, thus making all natural phenomena invariable in their courses. By this method prayers and supplications will no longer be maintained for invoking warm or cold weather. We look to the thermometer and barometer, and watch for areas of high and low pressure, knowing that, under the same conditions, the same phenomena will always occur, in spite of the anger, hatred, or compassion of some god.

The spark of civilization was first kindled in the East, where, at the time of the dawn of history, observed facts were already arranged in what we may call subjective systems. These facts were founded upon experience; man knew at this time how to shield himself from the forces of Nature as well as from the forces of man. He knew how to prepare and cook his food, was physician enough to cure by the use of herbs, biologist enough to distinguish different forms of life, geologist enough to know the lasting properties of different building material. But what is more, language, both written and spoken, was well enough advanced to give us the records of these early times. The fact that one hundred thousand men were forced to work for twenty years upon one pyramid shows that the art of government had advanced no little way.

But through all such knowledge ran pure religious superstition. Nothing existed for aught but the gods; nothing was of use or consequence save that which could apply to religion. Thus narrowed, it was impossible for the conservative minds of the East to

break the strong adherence to custom, which was carefully fostered by government. The people lived on from generation to generation, as their forefathers had done, satisfied with what they had, scarcely dreaming that there could be anything more to learn; indeed, they could not learn more without offending the gods. What Verschoyle says of art in Egypt — that "it was exactly that liberty of spirit that Egypt lacked; art was swathed in bands like a mummy, was forced into the same cold rigidity, and remained immovable like the monuments raised by a despotic empire, under a sky as unchanging as themselves"[1] — may be said with equal truth of all Eastern science.

Among these nations Egypt is the best known. It was governed by a despotic monarchy with divine attributes. The priests had strong influence, strongest after the fourteenth century B.C., but never gained absolute control of supreme power. Mena was the first of historic kings, and the date of his reign varies with different authorities, from 5702 (Boeckh) and 3623 (Bunsen), to 2700 and 2440 (English short chronology). According to Lepsius, the old empire was founded in about 3000 B.C. by Mena; the capital, Memphis, was named after him. The greatest pyramids were built between 2800 and 2700, by the kings who composed what is known as the "pyramid dynasty." About 2221 Amenemhat III constructed Lake Meri (*i.e.*, "lake of inundations"), a large reservoir for regulating the water supply of the Nile; and he built south of this the so-called Labyrinth, a large palace for ceremonial acts and sacrifices. About 2100 Egypt was conquered by the Hyksos, or Shepherd kings. These people were wandering tribes of Semitic descent, who were finally driven out of power by revolts headed by Thebes between 1800 and 1659. From this time the New Empire increased rapidly in power and extent. Under the new kings the Syrians and Ethiopians in the south were conquered; trips were made to Arabia and to the Euphrates. But the "golden era" for Egypt was from 1388 to about 1200, and the greatest name is Ramessu II (Rameses II), during whose reign Egypt was covered with magnificent buildings, and a canal was commenced between the Red Sea and the Nile.

In 730 the Ethiopians under Shabak conquered Egypt and governed for fifty-eight years, when the Assyrians, under Esarhaddon and

[1] J. Verschoyle, "History of Civilization," page 41.

his son Asshurbanipal, put an end to their reign and entrusted the country to twenty governors, most of whom were natives.

One of these governors, Psamethik (Psammethichus), in alliance with Gyges, king of Lydia, with the help of Carians, Phœnicians, and Ionians, made himself independent of the Assyrians, and sole ruler over Egypt, 653 B.C. Out of gratitude to his mercenary troops, he listened to their appeal and opened Egypt to foreigners, who immediately settled in various parts. This led to dissatisfaction among the warrior caste, for the Greek soldiers were favored over every one else. This dissatisfaction was the cause of their migration to Ethiopia, and thus began the decay of the empire.

This ends our short sketch of the history of Egypt; it is needless to go further, for in 525 the ancient country was conquered by the Persians under Cambyses, and with this subjection Egypt, as a nation, loses all historic interest, and her monuments alone show her place in the history of civilization. Science left to the Egyptians would never have gotten out of the ruts which they made for it. New peoples coming in, however, could accept the old ideas for what they were worth, and add to them new ideas and discoveries. Long before the conquest Egypt was known to other nations through the agency of the Phœnicians, the great carrying people of ancient times. To commerce alone do the Phœnicians owe their fame; we hear of them carrying Egyptian products to the East, and, in return, bringing spices and other Oriental goods. In this manner, ideas of Egyptian learning were brought to all neighboring peoples, and these, when the events we have mentioned made it possible, thronged into Egypt to partake of the numerous possessions for which that country was famous. The Assyrians, who were superior to the Egyptians in civilization and knowledge, as the latest discoveries show, had an opportunity to benefit by the Egyptian knowledge as well as to improve the Egyptians themselves; although it is doubtful if the latter would accept new ideas, because of their firmly grounded conservatism. However, the establishment of the Assyrian power in 653 B.C. was a grand opening for foreigners. The Phœnicians and Greek pirates had so filled the Western mind with ideas of the wealth and treasures offered by that vague land of myths, that, when the opportunity came, the Greeks were not slow to accept.

A brief review of the civilization of the East will show what it had to offer to the incoming peoples from the West. From the first, the Egyptians were favored by every force of Nature, and were almost compelled to observe. A remarkably clear sky, never overcast by clouds, and a dry atmosphere which allowed the sense of sight free range to observe the motions of the heavenly bodies, both aided the study of astronomy. The yearly overflow of the Nile, leaving vast fields of fertile mud, made artificial measurements of land absolutely necessary. The overflow of the Nile, again, was the cause of certain hydraulic arrangements for keeping out unnecessary water, if the flood registered too high on the Nilometer, or for the allowance of greater overflow if it registered too low.

At the time of the building of the pyramids, the Egyptians must have made considerable advance in civilization; they knew how to quarry rocks of the hardest stone, even granite, and transport them great distances. They raised huge monolith obelisks, and polished and carved their granite so as to last thousands of years. The Pharaohs divided the land into nomes, and these again into four parts as follows: (1) The chief town, with the seat of government, civil and military, and the center of the local religion; (2) the productive land, bearing the fruits of the Nile valley; (3) the marshes, where the Nile overflows and leaves deep pools not easily dried; (4) the canals, which were filled from the Nile, and used for irrigation when the flood retired. This act of the Pharaohs shows that there was considerable knowledge of geometry and hydraulics; practical geometry was necessary because the Nile overflow of mud obliterated the landmarks, necessitating a yearly measurement of areas; their canals and dams showed a certain acquaintance with practical hydraulics. Chemistry derived its name from Egypt, where it was known as the "sacred art." They seem to have had some chemical knowledge, but it was the result of chance discovery, and not at all scientific. They had no commerce, because their religion kept them from leaving their own country. Arithmetic was unknown to them; they expressed units by strokes, tens and powers of ten by fresh strokes. In medicine everything was specialized, and no physician could undertake to cure any ailment not in his special line. Egypt was a very healthy country, so that new diseases were uncommon. Doctors were required to practice according to certain established precepts

which were sanctioned by the priests. If a patient died under this treatment, nothing was said; but if a death occurred under the application of some new remedy, the penalty was very severe. It was the same in medicine as in every other thing Egyptian; bound down by iron laws, practitioners could learn nothing new, even if they so desired. As for dissecting the dead and learning facts in that manner, they would as soon have thought of burning their sacred bull for amusement.

While all this was good as far as mere knowledge is concerned, it was not science, nor were facts collected by scientific methods, but rather by chance or, perhaps, necessity; use alone sanctioned these facts, not principle.

In astronomy the Egyptians came nearest to modern scientific methods, but here their claims to the origin of the science must give place to those of their neighbors, the Chaldeans.

The first time marked by the Egyptians was the lunar month, and as the overflow of the Nile was the most important event of the year, they were led to divide the period between two successive overflows into twelve months of thirty days each. The inundation of the Nile coincided with the rising of Sirius, the Dog Star; hence the Egyptians, with that tendency of man to mistake coincidences for causes, soon attributed the yearly overflow to celestial agencies, through the rising of Sirius. Coming year after year, this soon came to be anticipated, and the calculation of the number of days elapsing between each rising soon followed; this calculation showed a period of about twelve lunar months, or nearly 360 days. But finding that by this the Nile rose about five days later each year, they soon learned to intercalate five additional days, making in all 365 days. It is uncertain when this first took place; some trace it back only as far as the time of the Shepherd kings, or about 2100 B.C. There is a curious myth told as to the origin of the five intercalary days. Thoth (Hermes), god of astronomy and calculation, plays at dice with the moon, and wins from her a seventieth part of the 360 days of which each year consisted; this fractional part ($\frac{360}{70 = 72}$) gives the extra five days which were consecrated to five gods. Still the astronomical year was six hours ahead of this, or one day in four years, 30 days in 120 years, and 365 days in 1,460 years. The Sothiac period, the period between successive heliacal risings of

Sirius, was 1,461 years; so that this extra unit goes to show that they made use of the additional day every four years in their calculations. "The period is called Sothiac, because the time assumed for its commencement was when Sirius, or the Dog Star, called by the Egyptians 'Sothis,' and consecrated to Isis, rose heliacally on the first day of Thoth, the first month of the Egyptian fixed year, the 20th of July of our reckoning." In the Rameseion, an astronomical monument in Egypt, there is a figure of Isis (Sothis) in the middle of a vacant space between the months Mesori and Thoth (last and first). It is inferred from this that the monument was in commemoration of a Sothiac period; the chronology of Egypt is favorable to this inference, as Rameses II or III lived during the fourteenth century B.C., and astronomical reckoning shows that Sirius rose heliacally on the 20th of July at Heliopolis in 1322 B.C. The Egyptians used their astronomy chiefly for astrological purposes; nothing was ever done with it by them, but the facts which they gained were used by the more imaginative Greek.

The Chaldeans were the first astronomers, and their method of astronomical study was infinitely better than that of the Egyptians, who were inclined to watch one star only, Sirius in particular, probably for the sole reason that their ancestors had done so before them. The Chaldeans studied the whole heavens, made a map of the celestial sphere, and were the first to establish the twelve signs of the zodiac. They, also, used their astronomy in religion, and for astrology. They could predict eclipses of the moon with a precision which leaves but little for modern science to improve. They fixed the tropical year within twenty-five seconds of the truth, the sidereal year only two minutes in excess. They also knew of the precession of the equinoxes.

But not only in astronomy were the Assyrians superior to the Egyptians; they had a system of weights and measures based upon a unit of about 500 millimeters, and this was the only scientific standard until the establishment of the metric system. It is a curious fact that these people began with ten and afterwards changed to twelve, probably because the latter number could be more subdivided than the former, which is, indeed, awkward, except for the ease of its multiplication; to the ancient Assyrians, however, this advantage of ten was lost, because the cipher was not then invented.

The Assyrians welded iron and bronze together better than it can be done today; their system of canals, dams, and locks for irrigation was more thorough than ours. They printed by means of revolving rollers, on which were engraved cuneiform characters. Assyria had more to offer to the Greeks than had Egypt; but, while Assyrian knowledge affected Greek learning, still Greek science is due more to the facts learned in Egypt. They did accept Assyrian art; this they could take while marching through a country — that is, they could see it — whereas science had to be studied, and the Greeks never remained in Assyria long enough for this.

The Phœnicians did not have much to offer in the domain of knowledge. Their functions were rather those of a go-between, to carry ideas from one nation to another with the exchange of commodities. They were, however, first-class glaziers and expert miners, and their dyes are famous to this day. To them we owe the origin of the alphabet in Europe, for they communicated letters to the Greeks, the idea being to represent the material object which the name of that object signified.

The aim of this article so far has been to show upon what facts science was based. Eastern peoples amassed details of knowledge, showed great intellectual activity, and made practical use of many arts; but we must seek in the Western mind the inauguration of the true scientific epoch. It was the Greek who threw away the subjective attitude and studied facts for their principles, rejected supernatural agencies, and made a systematic effort to detect the causes of all changes as inherent in the things themselves.

The facts, amassed in the East, furnished the Greeks a groundwork upon which to base their speculations; Thales, for example, who lived about 600 B.C., was the first philosopher to take advantage of the learning of Egypt. There he gained knowledge of practical geometry, which he transformed into the geometry of lines, an abstract subject, by the application of that speculative spirit for which the Greeks were famous. By reasoning, he showed that different parts of a geometrical figure may be obtained when certain other parts are given. This was something new in the history of thought, and at this point we may mark the beginning of that rearrangement of knowledge by which the religio-practical application of facts gave place to the theoretical. It was a long step towards the transition from the subjective to the

objective method of inquiry. Beginning with abstract reasoning of geometry, it spread, later, into all branches of science, seeking the different principles which cause different phenomena. Eastern nations were also speculative. The philosophy of the Hindus far transcended that of the Greeks in imagination, but was useless; while the Greeks were much more practical, and their philosophy was within the range of possibilities. It has been said that an imaginative mind is absolutely necessary for a scientific investigator. It was this mind that the Greeks possessed, although their imagination was a trifle too strong when, through it, they were led to explain the origin of the universe long before they were rid of the local ideas connected with the significance of certain words such as "form" and "matter," "upwards" and "downwards;" and this manner of speculating was the cause of their failure in science. No sooner did they make sure of one or two points, than they must need apply the same thing to analogous phenomena without the test of experience. In other words, they jumped at conclusions, were satisfied with logical explanations, and failed to follow up their conclusions with experiments. In many cases their wild guesses came remarkably near to modern scientific truths. Thus Pythagoras made the sun a glowing ball of fire about which all the planets revolve. Democritus asserted that "nothing can be made from nothing," and that all changes consist in the separation and rearrangement of particles; also that there exist nothing but atoms and empty spaces, and that the atoms affect each other only by impulse and pressure. Anaxagoras maintained that the moon had mountains and valleys, and that there had been grand epochs in the history of the globe. Some of the most striking features of the cult of Zenophanes have been reproduced by Newton.

In their philosophical speculations the Greeks sought after one thing only — an ultimate cause of the universe. In this search many scientific facts were collected as by chance, but the period when science was to be cultivated for practical purposes was not yet come.

Greek thought starts with geocentral and physical ideas. The earth is the grand object of the universe, and, as a necessary result, erroneous views of the relations and dimensions of the sea and air were prevalent. The philosophy of Thales, founder of the Ionian school, is usually summed up in the phrase, "All things are water;" and

to carry out this idea, he attributed all things to this first cause, water, the necessity of which in Egypt may have greatly impressed him. Thales is also universally recognized as the founder of Greek geometry and astronomy. He is said to have predicted an eclipse of the sun which took place May 25, 585 B.C. But this was impossible, because the mathematics necessary for such a prediction were not known until later. His discoveries in geometry, whereby he applied abstract reasoning to practical measurements, may be summarized as follows:

1. The relations of the three angles of a triangle to two right angles.

2. The first trace of the conception of geometrical loci, as shown by his proposition that an angle inscribed in a semicircle is a right angle.

3. The sides of equiangular triangles are proportional.

The philosophical doctrine of Thales was developed, during the course of three generations, by Anaximander, who chose as his principle, not water, but a corporeal element midway between fire and air on the one hand, and earth and water on the other; next by Anaximenes, who preferred air; last by Heraklitus, who chose fire because it was in constant change; if there is to be change at all, he says, it must be constant. All of these philosophers followed the same general plan of ascribing to the universe one ultimate material cause.

Pythagoras of Samos, like Thales, spent much of his time in travel; and after visiting Ionia, Phœnicia, and Egypt, finally settled in Crotona, where he founded the Italian school of philosophy. In his philosophy we find at once an illustration of the speculative tendency of the Greek mind; for this system, more advanced in thought than that of the Ionian school, is much more abstract. The principle or essence of all things is not considered concrete, like water, air, etc., but abstract. "All is number," said the great Samian; and by that he meant not merely that all things can be treated numerically, but that the composition and constitution of everything are determined by number. Virtue, for instance, is a harmony of certain numbers, on the same principle that one is the point, two the line, and three the plane. Pythagoras thus anticipated the modern chemist, who, in like manner, attaches significant numbers to the names of things, who takes hydrogen as unity, gives oxygen 8, sulphur 16, etc. Carrying out these principles, there is no substance whatever to which the chemist could

not give a number. So it was with the Pythagoreans, and they, carrying their numerical doctrine to the extreme, assigned certain numbers as the representation of a bird, a horse, or a man. Pythagoras also taught an emanation theory, for he considered that the source of all numbers is the One or unity, from which he derived his grand standard of harmonical ratio — the musical octave. He discovered the relations of the octave to the third, fifth, etc., by experiments which are used today in every course of lessons in acoustics; but no sooner did he ascertain these ratios than he jumped to the conclusion that he had discovered the world's secret, and so taught that harmony, proportion, and number rule all things. The planets numbered five, which, together with the sun, moon, and earth, are placed apart at distances determined by a musical law. In their rush through space, they give rise to a sound, the "harmony of the spheres," which we do not notice, because we have always heard it. With the Pythagoreans we have the first enunciation of the heliocentric theory of the universe; but they also believed in ghosts and demons, and supposed that souls can exist without the body, leading a sort of dream life. They identified the motes in the sunbeam with these absent souls.

The yearning of Greek minds for explanations, which would combine the present intellectual activity with the old polytheism, found no satisfaction in philosophy, and was equally futile in other branches of learning. Herodotus could not reconcile the inconsistencies of the Trojan War with his knowledge of human nature; Eratosthenes saw contradictions between the voyage of Odysseus and the truths of geography; so Zenophanes, founder of the Eleatic school, gave up the attempt to save the old ideas, and taught disbelief in polytheism and belief in the *One*. This *One* to him was God, who is without passion or motion, and is everywhere — "all eye, all ear, all thought." His followers, Melissos and Zeno, carried on his doctrines which he taught in verse. The latter affirmed his position by the *reductio ad absurdum* — a dialectical method which he was the first to employ. Parmenides, probably a pupil of Zenophanes, would not accept the universal mixture of the One — the Element — and the Many, but declared that these should be studied separately. Division in thought was the direct result; Empedocles and Anaxagoras studied the Many, Melissos and Zeno the One. Both divisions failed, and scepticism came in; suspicions were aroused that the mind of man can obtain

no perfect knowledge, and finally the opinion prevailed that we can have no reliable criterion of truth. The Sophists, or doubters, compared the different theories, showed how absurd each was, and thus all fell together. This period of doubt was the immediate forerunner of more correct opinions as to the nature of the world. In it came the reproduction of the heliocentric theory, with the necessary subordination of the earth, which endangered the old geocentric ideas and belief in the gods, thus giving rise to persecutions, and, in consequence, hypocrisy amongst philosophers. Socrates was the first to raise thought from this position of intellectual anarchy. He saw that physical inquiry was the cause of disbelief; so in his doctrines all mathematics and physics were to be abandoned. In this view he was followed by Plato, who taught the existence of a personal god, and belief in the future as well as in the past life of the soul. While not directly opposed to physical science, he considered it unworthy of much thought. All things are subservient to the intellect, and that alone should be cultivated.

As the first philosophic era was brought to a close by the Sophists, so the later Platonic era was thrown into confusion by the Sceptics, as evidenced by the conclusions of Pyrrho, which amount to saying that, if there can be no criterion of truth, there can be no certain ground of science, and so nothing remains but doubt. But this school of Sceptics never accomplished much, for it was about that time that the teachings of Aristotle began to turn men toward the study of science at Alexandria. It is impossible to pass over this period without some reference to Hippocrates of Cos as a premonition of the coming intellectual display of scientific inquiry at Alexandria. Hippocrates lived about 400 B.C., and to him is attributed the foundation of medicine as a science. The healing of wounds and cure by herbs had been known for centuries as an art, but Hippocrates is the first to attempt to base the practice of his art upon rational and scientific principles. His ancestors were disciples of Æsculapius, and offered prayers and sacrifices to the gods as remedial measures for disease. Philosophy and observation caused him to throw aside all traditions, and led him to declare openly his ways of curing, and to frankly acknowledge his failures. His doctrines ruled the practice of medicine for ages, and his ideas are still prevalent; so that today, when we speak of "bile," or of being "bilious," or of "humors," we use the phraseology of the famous

theory of Hippocrates, that the human body contains four humors, namely, blood, phlegm, yellow bile, and black bile — disease being caused by the undue accumulation of some one of these. This theory led to various remedies, such as bleeding, purging, blisters, and others, some of which are used to this day.

Scientific investigation of observed phenomena began with the Alexandrian school. In the great Museum at Alexandria the amassed facts collected in Eastern countries, were thoroughly examined and rearranged, and from them scientific principles were deduced for the first time. Before this, all had been art, or the realization of principles; as the art of the builder appears in the structure which he has erected, though he may never have thought on the abstract propositions on which its stability and strength depend. On the other hand, science is the theoretical discovery of these principles; it is speculative, not practical. The scientific builder sees that, under certain conditions, bodies must sustain each other's pressure.

It is fitting that Egypt should be the site of the beginnings of science, as it was the site of the beginnings of her parent, art; and, before entering into this scientific epoch, inaugurated at Alexandria, we may pause.

AUTHORITIES.

WHEWELL — History of the Inductive Sciences.
DRAPER — Intellectual Development of Europe.
VERSCHOYLE — History of Ancient Civilization.
LEWES — Aristotle.
SPENCER — Genesis of Science.
BAX — History of Philosophy.
ROUTLEDGE — Popular History of Science.
SHARPE — History of Egypt.
KENRICK — Ancient Egypt under the Pharaohs.
WILKINSON — Ancient Egyptians.
ENCYCLOPÆDIA BRITANNICA — "Assyrians," "Phœnicians," "Thales."
TYLOR — Anthropology.
PLOETZ — Epitome of Universal History.

DISSENSIONS IN THE AMERICAN CHURCHES OVER THE SLAVERY QUESTION; ESPECIALLY AS ILLUSTRATED IN THE PRESBYTERIAN AND METHODIST EPISCOPAL DENOMINATIONS.[1]

By BENTON STURGES, S.B.

The history of slavery agitation in the American churches falls naturally, as does that of political abolition, into two distinct periods. The first, extending from the earliest attacks upon the slave trade by the Society of Friends, down to the years following the Missouri Compromise, is essentially an era of belief in abolition, churchmen and statesmen alike holding anti-slavery opinions almost without exception. But these abolitionists of the "Old School" put trust in schemes of colonization and emancipation through sale of public lands, and, moreover, were many of them Southern men. Even up to 1826 the North could claim scarcely a fourth of the hundred and one anti-slavery societies, while in 1840, out of two thousand, almost all were of the North or West.

The beginning of the second period is marked by a growing aggressiveness on the part of the South. State legislatures passed repressive laws against emancipation and against the education of the slaves, and with Jackson's administration began a general system of vigilance committees, who soon terrorized the Southern abolitionists into silence, or caused their emigration.

The abolitionists, too, became in this period more violent than before, and as a Southern minister said, used measures which, "instead of making an impression upon the hearts of the slaveholders, raised a protuberance." The churches, after carrying their temporizing policy so far as to unsay all their former testimony, ended in disruption, and hastened the division of the country. It was said that Dr.

[1] Thesis, Course IX, 1890.

Palmer, of New Orleans, "did more good in the rebel army for the cause of secession than ten thousand men," and the influence of such a man as James H. Thomwell was incalculable.

First Period, to 1830.

The honor of initiating the anti-slavery movement in America belongs indisputably to the Society of Friends, and the steadfastness with which they maintained and asserted their convictions distinguishes them honorably from the larger denominations.

The subject of slavery seems first to have troubled the consciences of certain Germantown Friends as early as 1688, when they presented a protest at their Monthly Meeting concerning the unlawfulness of buying and keeping negroes, basing their arguments upon the Golden Rule. "There is a saying that we shall doe to all men like as we will be done ourselves. Being now this is not done in the manner we would be done at, therefore we contradict and are against this traffick of men-body." The Monthly Meeting, however, considering it too "weighty" for them to "meddle with," "ye tenor of it being nearly related to ye truth," passed it on to the Quarterly Meeting; whence, for the same reasons, it was transferred to the Yearly Meeting of Philadelphia, and here also failed to procure decided action, "it having so general a relation to many other parts." Thus the first agitation died out for the time being, until 1696, when the Yearly Meeting again took it up, advising Friends "not to encourage the bringing in of any more negroes."

In 1711 the attention of the Yearly Meeting was again called to the subject by the Chester Monthly Meeting. Though the most southerly of all the Philadelphia connection, it was here that the greatest persistence was shown. It even appears that a certain bitterness of feeling must have been aroused even at this early date, since, in 1715 the Chester Friends again appealing, the Yearly Meeting seems to have found it necessary to exhort all Friends "not to reflect on one another, either in public or private, concerning the detaining or keeping of their" (slaves) "servants." The following year the Chester Quarterly Meeting again agitated the question of buying negroes. Their minute, however, met with but cold reception in the Yearly Meeting, which advised "that Friends generally do, as

much as may be, avoid buying such negroes as shall hereafter be brought in, rather than offend any Friends who are against it," adding, "Yet this is only caution and not censure." In 1729 another appeal was made, and after the action upon it had been laid over until 1730, the Yearly Meeting finally disapproved the buying of imported negroes, as well as the importing them, which was already a breach of discipline. In 1735 this "advice" was repeated, and thereafter annually, with the exception of 1740, until 1743.

By this time the members of the Society had everywhere become thoroughly alive to the great evils of the slave trade, and were actively preaching its abolition. As early as 1718, William Burling, of Long Island, had published a tract on the "Unlawfulness of Slavery," followed by others. In 1729 Ralph Sanderford, a "money-getting Quaker merchant" of Philadelphia, circulated his "Mystery of Iniquity," and in 1733 Elihu Coleman issued his "Testimony against that anti-Christian Practice of making Slaves of Men." But greatest of all was Anthony Benezet, the French philanthropist, who, joining the Society of Friends, emigrated to Philadelphia in 1731, and devoted his energies to preaching and writing tracts in behalf of the cause. John Woolman, too, in 1746, began his tour of the South, preaching the "sin of slavery," and that "liberty is the natural right of all men equally." In 1754 he published his "Considerations on the Keeping of Negroes."

The desire to be rid of slavery was unanimous in the Yearly Meeting of 1758, and John Woolman, who was fast becoming a central figure, was appointed one of a committee to visit all slaveholders and urge emancipation. From this time on, the subject received most frequent attention, and after 1767 the subordinate meetings made regular statements concerning the number of slaveholders among them. In 1778 there is record of seven slaveholders having been disowned, and in 1783 the Yearly Meeting was declared free of all connection with the evil.

The history of the movement in the other Yearly Meetings is of a similar character, and in New England slaveholding was made a "disownable offense" even earlier than in Pennsylvania. The first mention of any action is in 1716, when the Monthly Meeting of Dartmouth sent a query to the Quarterly Meeting of Rhode Island, asking "whether it be agreeable to truth for the Friends to purchase

slaves and keep them for a term of life;" and in the same year the Friends of Nantucket made a declaration in the negative. Fifty years later the matter was prosecuted vigorously, and in 1782 the Yearly Meeting reported, "We know not but all the members of this meeting are clear of that iniquitous practice of holding or dealing with mankind as slaves." Two years later a rule was passed making any Friend refusing to emancipate his slaves liable to punishment as a "disorderly walker;" but no such case ever arose.

The New York Yearly Meeting was somewhat slower to move, but it reported no slaveholding members only five years later than the New England Yearly Meeting, 1787.

The first step taken in the Virginia Yearly Meeting was in 1757, when a query was adopted asking, "Are Friends clear of importing or buying negroes to trade?" But no unanimous action could be taken until 1768, when it was declared henceforth a "breach of discipline for any member to purchase a negro or other slave," and in 1784 the Monthly Meetings were authorized to disown any member who should refuse to emancipate his slaves.

Slavery once and forever abolished within the Society, the Friends began earnestly memorializing Congress and the different State legislatures. The first petition to the General Government was from the Friends of the Middle States in 1783, who repeated the action in 1790. On this last occasion they were "indecently assailed, and ridiculed as 'Shaking Quakers.'" In Jefferson's administration, however, they received greater respect, and their petitions were henceforth of regular occurrence. Previously, notable petitions had been presented in 1792, 1794, and 1797.

In the first years of the present century the Friends in the Southern States, though never relapsing into the practice of holding slaves themselves, began to decrease rapidly in numbers. Especially was this true in the Carolinas, where the growing intolerance of the pro-slavery faction led to frequent emigration on the part of the Friends. Numbers of them settled in the White River Valley, Indiana, which in later years became the chief line of the underground railroad, and it was largely due to them that in 1806 Jonathan Jennings, at first ridiculed as the "beardless boy" and "the cold potato," was enabled to advocate with some success the policy of "No Slavery for Indiana." In 1816, at the drawing up of the

State constitution, the petitions of these Friends were again influential upon the right side.

In the North, Friends were everywhere prominent in the foundation of anti-slavery societies, and their action in aiding fugitive slaves to escape, and in many cases even enticing them to do so, called forth the censure of almost all the most prominent advocates of anti-slavery, Washington among them.

About the period of the Missouri Compromise, the general movement appeared first to falter, and though individuals continued to preach abolition, and pamphlets were still issued by the various meetings, Friends partook of the prevalent contagion. The old Abolition Society of Philadelphia itself, in which they had been so prominent, died a lingering death in 1829, having shown symptoms of decay as early as 1807, when its meetings were made triennial instead of yearly.

Among the other denominations in this first era of abolition, none could claim opinions nearly as advanced as the Friends. In none was slaveholding declared a "disownable offense," yet all were distinctly anti-slavery, in different degrees. The Baptists and Methodists were most pronounced. Being drawn from the lower classes, they felt sympathy for the slave class rather than for the masters. The Presbyterians were less strongly anti-slavery, and the Episcopalians probably least of all. As the records are most complete in the case of the Presbyterians, I shall consider them first.

The first official notice taken of the subject of slavery was in 1774, when a representation respecting a mission to Africa was presented to the Synod of New York and Philadelphia, then the highest judicature in the Church, by Rev. Dr. Ezra Stiles and Rev. Samuel Hopkins. In this paper the question of slavery came up, but action on that question was deferred to the next meeting of the Synod. At this meeting, however, nothing was said of it, nor was it referred to afterwards. In fact, until 1787 the subject was left without any formal consideration. Then the Synod took action, and finally expressed its approbation of abolition, urging all Presbyterians to use the most "prudent measures" towards final abolition, but advising preparatory instruction of the slaves rather than immediate emancipation. The following year the General Assembly was first organized, and in 1793 this body reëndorsed the action of 1787 by having

it printed in the extracts of their minutes. They were led to do this by a memorial presented "under cover" by Warner Miller, a Friend. Friend Miller was the same man who, the year before, had presented a petition to Congress upon the subject of slavery, which petition a member from South Carolina had called "mere rant and rhapsody of a meddling fanatic, interlarded with texts of Scripture."

The next important action was that of 1815, chiefly due to a petition from the Synod of Ohio (an intimation of the part the West was soon to play), and to petitions from certain elders. The Assembly now declared that "although in some sections of the country, under certain circumstances, the transfer of slaves may be unavoidable, yet they consider the buying and selling of slaves by way of traffic, and all undue severity in the management of them, as inconsistent with the spirit of the gospel. And they recommend it to the Presbyteries and Sessions under their care to make use of all prudent measures to prevent such shameful and unrighteous conduct." The petitioners were then referred to the former action of 1787, 1793, and 1795.[1]

It was at this Assembly of 1815 that a note was first publicly introduced to Question 142 in the Catechism, to the effect that "man-stealing" is one of the forbidden sins, and that by "man-stealers" are meant all those who "bring off slaves or freemen and sell or buy them." This note was erased in 1816, by the General Assembly, upon an inquiry by the Presbytery of Philadelphia concerning notes in general, but the General Assemblies of 1817 and 1818 both decided in direct opposition to the action of 1816. In 1818 the resolutions were the strongest in their anti-slavery character of any ever voiced by a General Assembly of the Church, before or after.

The report made this year was indeed the strongest utterance of the abolitionists from this time until the final division of the Church, and though it soon became a dead letter, at least in the slave States, and was even declared rescinded by several Synods and Presbyteries, it remained unrepealed by the General Assembly, and was thus the stated law of the Church throughout the whole struggle.

The report, as unanimously adopted, read as follows: "It is manifestly the duty of all Christians who enjoy the light of the present

[1] The action of 1795, in answer to an overture from the Presbytery of Transylvania, Kentucky, was merely a reaffirmation of former sentiments.

day to use their honest, earnest, and unwearied endeavors as speedily as possible to efface this blot on our holy religion, and to obtain the complete abolition of slavery throughout Christendom, and, if possible, throughout the world. The manifest violation or disregard of the injunction here given, in its true spirit and intention, ought to be considered as just grounds for the discipline and censures of the Church, and if it shall happen that a Christian professor in our communion shall sell a slave who is also in communion and good standing with our Church, contrary to his or her will and intention, it ought immediately to claim the particular attention of the proper Church judicature; and unless there be such peculiar circumstances attending as can but seldom happen, it ought to be followed, without delay, by a suspension of the offender from all the privileges of the Church, till he repent and make all reparation in his power to the injured party."[1]

After this stupendous effort, however, the General Assembly seems to have felt satisfied that its duty was done, and it lapsed into the most unaccountable and lengthy silence, taking no action of any kind upon the subject until 1836, when both North and South were ablaze, and the pro-slavery men had become the aggressors. Moreover, it does not appear that the action had any other effect than to arouse the anger of the Southern members at a later date, since the rules set forth were never enforced upon a single slaveholder.

The case was widely different in the Reformed Presbyterian connection. Though scattered in considerable numbers over Vermont, New York, Pennsylvania, and South Carolina, the denomination claims notice, not so much on account of numbers, as from the early date at which its members emancipated all their slaves, and the heroism with which this was accomplished in perhaps the most thoroughgoing slave State in the Union.

They were descendants of the old Scotch Covenanters, and held rigidly to their doctrines. They would not in any way recognize the National Government by holding offices under it, nor would they hold communion with other churches, and in their "Doctrinal Testimony," published in 1807, they declared slaveholding a bar to communion.

Slavery had been agitated for some time in the Northern congrega-

[1] The Church and Slavery. By Albert Barnes.

tions, when, in November, 1800, James McKinney and Samuel B. Wylie, as a committee, visited Rocky Creek, South Carolina, where a Mr. Donnelly had accepted a call and was to be ordained and installed. Before the celebration of the communion the committee stated the decision of the Presbytery at its last meeting, to the effect that slaveholders should not to be admitted to the Lord's table. "Thereupon," Dr. Wylie relates, "the committee were no less surprised than delighted to find with what alacrity those concerned came forward and complied with the decree of the Presbytery. In one day it is believed that in that small community of Reformed Presbyterians not less than *three thousand guineas* were sacrificed on the altar of principle. Only one refused to emancipate his negroes, and his location was beyond the limit of the State of North Carolina." From this time no slaveholder was admitted to this Church, either in the North or South, until 1830, when the denomination was much split up by the New Light Controversy.

After the strong position which John Wesley, the founder of Methodism, had taken upon the question of slavery, it is not remarkable that the early members of that Church in America should have been among the strongest opponents of the system. Wesley had stigmatized slavery as "the sum of all human villainies," and American slavery as "the vilest that ever saw the sun." Francis Asbury and Thomas Coke, the first two American bishops, were as pronounced as Wesley, and Freeborn Garretson ranks with the very first of early abolitionists.

Notwithstanding these influences, however, the first anti-slavery ordinance passed by the Church resulted, in 1779, in a secession of the entire body of Southern preachers, numbering more than half the whole. A Southern Conference was held at Fluvanna, Virginia, while Mr. Asbury held a separate one in Delaware, and, although the objectionable ordinance was withdrawn in 1780, the two bodies did not meet together again until 1784. This ordinance declared slavery to be "contrary to the laws of God, man, and nature, and hurtful to society; contrary to the dictates of conscience and pure religion; and doing that which we would not that others should do to us and ours." It further demanded promises of all itinerant ministers to set free their slaves, if they possessed any.

In 1784 the two divisions came together again, and the Church was first regularly organized. The stringent measures which were

now passed are rather surprising in light of the recent division upon the subject. A rule for gradual emancipation was adopted, which all members must sign within twelve months or withdraw from the Society. Those who refused were to be prohibited from communion and expelled. A note was appended, however, which stated that the rules were "to affect members no further than they were consistent with the laws of the States in which they were residing," thus excepting Virginia, where members were to be allowed two years. Six months later the rules were suspended altogether, and never afterwards introduced.

Emancipation by private individuals did, however, take place to a considerable extent, and Asbury, in his journal, states that in Maryland almost all members had freed their slaves. This was in 1788.

In 1796 new rules were passed, but of a weaker character. It was now forbidden to sell slaves, though purchase was permitted on condition of promises of future emancipation, the Quarterly Meetings to determine at what period. Slaveholders before entering the Church should be spoken to "freely and faithfully" upon the subject of slavery, and an annual address should be drawn up urging gradual emancipation. This was omitted, however, the very next year.

The action henceforward seems to have been all retrograde, and, writing in his journal in 1798, Asbury says: "It appears to me that we can never fully reform the people until we reform the preachers, and that hitherto, except purging the travelling connection, we have been working at the wrong end."

In 1804 even the rule against selling slaves was modified, and in a volume entitled, "Doctrine and Discipline of the Methodist Episcopal Church," published in that year, the following appears: "Any member who sells a slave without his consent shall be expelled *unless for humanity or necessity*, as shall be judged by committee of male members of the Society, and upon purchase the Conference shall decide in how many years the slave shall be declared free;" moreover, Georgia, North Carolina, South Carolina, and Tennessee were declared exempt from the rule. In 1808 all rules relating to private ownership of slaves were stricken out of the Discipline altogether, and the matter of sale or purchase delegated to the Annual Conference. After this the General Conference took no further action for nearly thirty years, and after 1820 even what remained of the General Rule was regarded in the South as a dead letter.

In the Baptist Church, divided as it is into numerous and entirely independent Associations, there is no one source of authoritative and general information. It is therefore only from scattered and exceedingly scanty records that a general view of the position of the denomination at large can be drawn. That Baptists were strongly anti-slavery in the last century is at least certain. Drawn as they were from the lower classes, and led by an almost universally uneducated clergy, it is natural that their sympathies should have been rather with the slaves than with the slaveholders. Thus in 1789 we find a general committee of the Virginia Associations passing resolutions of a highly satisfactory character, and expressing hopes that their "Honorable Legislature" would soon "proclaim the 'Great Jubilee.'"

In Kentucky the crusade was begun in 1787 by Joseph Carman, an elder in the Church, who afterwards became prominent in Ohio as an immediate abolitionist. In 1804 a number of ministers calling themselves the "Friends of Humanity" took such extreme views as to call forth the censure of their Association, at which they withdrew and formed an independent Association. In another part of the State an Association numbering twelve churches actually refused church fellowship to slaveholders. Until the excitement over the Alien and Sedition Acts in 1798, the "Free State" sentiment had prevailed throughout all Kentucky.

Second Period, 1830 to the Civil War.

Many causes combined to effect the change which popular opinion underwent at the close of the first abolition era. These causes were threefold in character, namely, political, commercial, and religious.

The political causes grew out of the Louisiana Purchase and the subsequent rapid development of the West which took place in Jefferson's administration. As the new Territories pressed for admission, the pro-slavery faction, alive to the importance of securing them as slave States, used every endeavor to accomplish this end, and the "Solid South," which had appeared for the first time in 1796, now took definite and permanent form as a great pro-slavery party in the struggle prior to the Missouri Compromise.

The great commercial cause was the increased importance of the cotton trade, and the consequent increased value of the slaves. It was supposed that slavery was absolutely the only system by which the plantations could be cultivated, and that emancipation meant the total ruin of the South. A very singular pro-slavery volume containing essays on the commercial, moral, theological, and ethnological relations of slavery, traces, in an article entitled "Cotton is King," a very curious parallel between the growth of the cotton industry and the growth of abolitionism.[1] It might much more directly be compared with the growth of the pro-slavery tendencies of the people whom cotton supported. In fact, as Mr. William Jay said in commenting upon Daniel Webster's pro-slavery speech: "It is now a matter of cool New England calculation. The cotton interests of Massachusetts call for it, and the gentry of Boston are cheering on their senator in his strange and reckless course." So great was the domination of cotton, that churchmen and statesmen alike feared nothing so much as offending the South; while the latter, realizing her dictatorial position, became more exacting and arrogant every day. The calls of the South Carolina papers for non-intercourse with Northern cities where abolitionism existed were answered by anti-abolition riots in New York and Pennsylvania, where bonfires were made of anti-slavery publications.

The religious causes were resultant upon those already named, and incident upon the great religious revival which spread throughout the country in 1815. Philanthropic societies of all kinds now sprang up, and all that were closely allied with one or another of the religious denominations assumed a pro-slavery character. Foremost among them was the Colonization Society. This had been proposed in 1800, and even then, outside of its benevolent mission, was advocated as a means of removing "persons obnoxious or dangerous to the peace of society." In 1816, when it was founded, its president[2] and nearly all the members of the managing committee were slaveholders, and

[1] Philadelphia was especially excepted in these articles.

[2] Judge Washington, shortly after becoming president, shipped fifty-four slaves to the New Orleans market. Charles Carrol, the second president of the Society and one of the signers of the Declaration of Independence, owned nearly one thousand slaves. James Madison, the third president, left one hundred slaves to his heirs at his death, and Henry Clay, the fourth, has been stigmatized as the man "who has done more for slavery and said more against it than any man in public life." Garrison, in his "Thoughts on Colonization," collected a great accumulation of material to show its pro-slavery character.

though many of its earliest supporters, Dr. Hopkins and Dr. Thomson among them, were inspired with purely philanthropic motives, it received its heartiest endorsement from the pro-slavery interests of the South. Here the authorized agents of the Society solicited contributions on the stated grounds that, by removing the free blacks, the slaves would become much more valuable; and the Southern planters responded with the same alacrity which would be manifested today in any great money-making enterprise. The South, indeed, looked upon colonization as "a drain for the excessive increase," and it has been called "an artificial antidote to nature's cure for slavery."

The churches, especially in the South, were warm in their support, and resolutions were passed again and again, expressing "entire confidence in the benevolent intentions of the American Colonization Society." Contributions for it were regularly taken in almost all the churches.[1]

One of the most significant evidences of the enthrallment of religion to the love of gain was the appearance now of the so-called "Godward side of slavery." Rev. James Smiley had been a man of strong anti-slavery convictions until he became the owner of a number of slaves through a second marriage. A most remarkable change then took place, and at the meeting of the Synod of Mississippi in 1834,[2] in an opening sermon he argued strongly for the righteousness of slavery as justified by the Bible. The sermon was almost universally condemned by the rich planters of the region, and in the following year, when he published his book, "Smiley on Slavery," the Mississippi Synod would give it no countenance, and one of the Natchez book-sellers actually refused to keep it on sale. The sentiment soon changed, however, and this new avenue once open to pro-slavery divines, they soon attained a high rate of speed upon it.

---

[1] Maryland passed an act appropriating moneys to the Colonization Society, which stated that, "should the negro refuse to be transported, he should be arrested and *forcibly taken beyond the limits of the State.*" Other States did the same. The victims were not, as an English writer said, "glad to jump out of the frying-pan into the fire," but indignation meetings of free blacks were held throughout the country.

[2] This was not the first appearance of "Bible slavery" in the country, as Dr. Cheever supposed. In 1819 Duff Green had published "The Bible Justifies Slavery," in St. Louis, and in 1823 Rev. Dr. Richard Furman ("that great and good man whose name still sheds a pious fragrance throughout the limits of his acquaintance"), in a communication to the Governor of South Carolina, had defended slavery on Scriptural grounds, while proclaiming the "pernicious tendency of free colored population."

There was not a text in the Bible which could not be turned to account by Southern logic.[1] The desire to secure the authority of one of the ten commandments led to the following: "Thou shalt not covet thy neighbor's man-servant. Then it must be right for him to own him, or it would not be wrong to covet him. Therefore slavery is a divine institution."

Owing to all these causes the hopes of the "moral" abolition party, in 1831, to obtain the support of the religious denominations, met with only the most discouraging results. The church organizations themselves were in advance of public opinion in its downward course, and had, in fact, forced pro-slavery opinions upon their members. It was only after abolitionist excitement had reached an extreme height that the church assemblies would do even so much as recognize it. Individual clergymen did, of course, take most prominent positions in the abolitionist ranks. But those who took the strongest stand were, as a general rule, far from orthodox. Theodore Parker admitted that the testimony of the Bible favored slavery, and made this an occasion for sneering at the idea of divine revelation. Channing had certainly drifted far from his early ideal of Puritanism. Rev. Henry J. Van Dyke asserted that "in this country all the prominent leaders of abolitionism, outside of the ministry, had become avowed infidels; and all our notorious abolition preachers have renounced the great doctrines of grace as they are taught in the standard of the reformed churches."

It was the clergy in the American Anti-Slavery Society who began the troubles leading to division there. In 1833 the question of allowing women to address the meeting was brought up. Mr. George Thompson, addressing the Glasgow Anti-Slavery Society in 1841, spoke of it as follows: "When the abolitionists were few in number, despised, poor, and everywhere spoken against, they kept together like sheep in a storm, or at midnight when the howling of the wolf is heard. The cause went on. The number of abolitionists became greater and greater. Now the Reverend So-and-so joined the Society, after a great many 'ifs' and 'buts,' and then a Reverend Dr. So-and-so joined also, after a great many more. And some of them did not like the forwardness of the women. We seldom like those

[1] That of the North was often little better; for example: "'Ye shall buy of the heathen.' There are now no heathen. Therefore you cannot now buy at all."

who outstrip us in zeal." Thus it was that this growing organization received its death-blow from those who should have been its chief support.

Owing to its long silence upon the subject of slavery, the position of the General Assembly of the Presbyterian Church was somewhat ambiguous at the beginning of the second epoch. By some it was called the "Bulwark of Slavery."[1] By others in the North it was assailed no less than in the South as "A great Anti-Slavery Society." But while the North was to a great extent conservative, and the Garrisonian faction was but small, the South had become overwhelmingly pro-slavery. A letter in the Boston *Centinel* for May 29, 1833, from North Carolina, stated: "The moment that interference with the condition of our slaves is seriously attempted by any considerable party in the non-slaveholding States, that moment the Union is at an end. And I pledge myself that not even an attempt to settle a question growing out of the agitation of slavery would be made on the floor of Congress. The Colonization Society is gaining the confidence of the whole South.[2] I rejoice that the abolitionists are running tilt against it."

It is about this period that the abolitionists in the South made their last attempts in the Synods and Presbyteries of the Church. The Synod of Kentucky debated for two days over an overture declaring slavery to be "a great moral evil and inconsistent with the Word of God." Action was then indefinitely postponed. Next year it was introduced again, and a committee appointed to draw up a plan of gradual emancipation; but no formal action was taken. The report of the Synod in 1835 was strongly pro-slavery, and the effect of this action was felt throughout the Church. The Synods of South Carolina and Virginia had passed resolutions in favor of slavery the year before. In fact, by 1835 Kentucky was the only slave State in which free speech had not perished. Before Jackson's administration lynch law had been seldom, if ever, exercised upon abolitionists, but from this time on it was universal.[3] In the Synod of Virginia, 1835,

---

[1] James A. Birney published a pamphlet under that title, Boston, 1843.

[2] He might have added, and losing that of the North, and consequently going into bankruptcy.

[3] This evil was much aggravated by the wild rumors which went through the South subsequently to the Southampton slave insurrection in 1831.

a paper was read on the "Views of Scripture," in which it was asserted that slavery was recognized by Scripture in "precisely the same way as the other domestic relations of life," and, though with some dissent, resolutions were passed condemning the actions of the abolitionists. Dr. Carrol compared the latter to an eagle carrying off a lamb, and, suddenly convinced of injustice, letting it drop.

In the North, especially in the West, the local Presbyteries were beginning to take anti-slavery action. The Presbytery of Chillicothe, Ohio, was foremost in this. In 1829 "Messrs. Gilliland and Crothers were here appointed a committee to prepare a pastoral letter to the churches under our care, on the subject of slavery, and report at the spring meeting of the Presbytery." They prepared two, and both were accepted and printed, 1,800 copies being circulated. They were similar in character, and urged non-communion with slaveholders. In 1833 the same Presbytery adopted another strong paper, a copy of which was sent to the Synod of Mississippi. And it was upon the motion of Dr. Samuel Crothers, of the Chillicothe Presbytery, that in 1835 the Synod of Cincinnati passed a resolution declaring the "holding of slaves for gain a heinous sin and scandal." In 1836 the Michigan Synod declared itself for immediate abolition.

In the General Assembly there had been no action whatsoever. Memorials, which had been submitted in great numbers, were entirely ignored or immediately tabled. In a letter from the stated clerk of the Assembly of 1834, printed in *The Philadelphian* of January 23, 1834, the fact is made clear that an anti-slavery overture, and a bundle of pamphlets for distribution, had been received, but excluded from the House by the Committee of Bills, the pamphlets being used as waste paper. The letter says: "The General Assembly has ever acted in relation to this business in resisting all the violent movements of absolute, universal, and unconditional abolitionists."

After the stormy year of 1835, "Mob Year," there seemed to be a growing presentiment that the General Assembly was to take a decisive anti-slavery stand; several of the Synods took independent action before the Session. In Missouri the Synod passed resolutions condemning the abolitionists. In Illinois, on the contrary, it was resolved "that the practice of slaveholding by a professed Christian is a most heinous and aggravated sin, and ought to subject the perpetrator to the discipline of the Church; and that this resolution,

with the former, recommending use of the proper means for speedy emancipation, shall go into the next General Assembly." This action in Illinois alarmed the newspapers in the South. The Columbia (S. C.) *Herald* urged all Presbyteries "to send full delegations to defeat it." The Charleston *Observer* predicted that "the next General Assembly would be the last to convene under the then organization." It further published advice to the delegates stating "that as soon as the discussion of the morality of slavery should come up they should unanimously retire from the Assembly, and not hold themselves bound by its proceedings."

The General Assembly met May 23, 1836. On the subject of slavery, Mr. Miller made the first report: "Resolved, that it is not expedient for the Assembly to take any further order in relation to this subject." This failed to pass, and a minority report declared "that slavery is a heinous sin, and that it is the duty of every one, and especially of every Christian, to free himself from it, and bring about the emancipation of the slaves in these United States and throughout the world." The whole question was now, however, indefinitely postponed under the following motion of Dr. Hodge: "Inasmuch as the constitution of the Presbyterian Church, in its preliminary and fundamental principles, declares that no judicatory ought to bind the conscience in virtue of their own authority, and as the urgency of the business of the Assembly and the shortness of the time during which they can continue in session render it important to deliberate and decide judiciously on the subject of slavery in its relations to the Church, therefore, Resolved, that the whole subject be indefinitely postponed."

The desire for church division now prevailed widely in the South. An anti-slavery member of the Kentucky Synod, writing July 6, 1836, expressed great fears of a secession there, and a correspondent of the *Southern Religious Telegraph* wrote, "I hope such another Assembly will never meet but once again, and then only with full and delegated powers." The editor commented: "A crisis has come; if there can be no compromise, division must be tried." The Presbytery of Concord, North Carolina, and the Presbytery of South Carolina both declared in favor of division; and the Synods of Virginia and South Carolina expressed similar opinions.

An opportunity now occurred in the Old and New School controversy. In 1837 the Old School at last secured a majority in the General Assembly, and decided to exclude the four most objectionable Synods, viz., the Western Reserve, Utica, Geneva, and Genesee, as it happened, all strongholds of the abolitionists. Rev. Dr. Baxter in advocating their excision openly argued that they would thereby "get rid of abolition."

The New School men immediately held a convention at Auburn, and there laid plans of opposition. In 1839 the commissioners of the four exscinded Synods were at first refused recognition in the General Assembly, and only received it by an over-ruling of the Moderator's decision. After the Session had been adjourned, the Old School remained and organized themselves as a separate church, taking possession of the books and other effects of the Assembly. The matter was now carried into the courts, and the law decided in favor of the New School. This decision, however, was over-ruled, and a compromise finally effected.

The Old School now continued to maintain its policy of conservatism, and after declaring its approbation of the objects of the American Colonization Society and deciding upon a general collection to be taken up for it, did nothing further regarding slavery or the negroes until 1845.

In the New School, too, conservatism continued to rule, but not to the same extent; efforts were at least made, though in this first year's Assembly a speaker was called to order when he attempted to speak of slavery and of the action of 1818.

Notwithstanding their conservatism, ministers were being drawn more and more into the struggle. Conventions of ministers were held in Worcester, Massachusetts, and in Hartford, Connecticut, and though the resolutions were usually of a mild form of abolitionism, with qualified statements, still the discussions bore fruit in the ranks of the younger ministers. This was especially the case among the theological students.

At Lane Seminary, Arthur Tappan set abolitionist debates on foot, in which Theodore D. Weld and Henry B. Stanton, at that time students, took part, and upon the prohibition of such proceedings by the trustees, four fifths of the students left, and camping out until a house could be provided for them, kept up their studies alone. In

1835 they were received at Oberlin, which henceforth became a hotbed of abolition and a general depot for the underground railroad.

The New School was held back in its desire to become free from connection with slavery by a still greater desire of retaining the churches of the border States, which were now wavering in the balance. Standing in this position, urged to take action by the abolitionists of the North and threatened with secession by the border States if they did, the General Assembly "solemnly" referred the whole matter to the lower judicatories, hoping thus to shift the responsibility. In 1840 the subject was again brought up, but only to be indefinitely postponed.

In 1843 memorials demanding action were again most pressing. Western New York, Ohio, and Illinois made especial efforts to secure it, and an important question, resulting from the decision of 1839, now came up. The Synod of Cincinnati had excluded certain slaveholding preachers from its pulpits, and Dr. Ely argued that such action was outside of its constitutional powers. Mr. Barnes maintained the other side. The decision of 1839 was reaffirmed. There was also much debate on the Scriptural relation of slavery. "If Brother Beecher," said Rev. Dr. Wisner, "had been in the place of good old Abraham, and God had told him to take his only son Isaac and put him to death, Mr. Beecher would look up and say, 'Why, Lord, it is contrary to the great principles of your government for me to take the life of my son; I can't do it.' And so Mr. Beecher would refuse to obey a positive precept because it conflicts with what he thinks is a *great principle.* But if God tells me to lay my wife upon the altar, it shall be done." Nathaniel West, a well-known abolitionist, urged the Assembly to "keep amidships as the best place to avoid those internal revolutions to which they were subject who would go upon extremes." It was finally voted that it was "not for the edification of the Church for the Assembly to take any action on the subject of slavery."

This timid policy called forth more local action and more urgent appeals. The Synod of Genesee declared, "The Church should take action for entire extinction of slavery." It did, however, condemn all disorganizing measures of the abolitionists. The New York *Evangelist* urged upon the Presbyteries the importance of selecting delegates who would "do their duty should the subject of slavery

come up." The Ithaca Presbytery, September 4, 1844, declared that the time had arrived when every church should condemn slaveholding members, declaring at the same time the system to be a "heinous sin." The Montrose Presbytery, November 2, 1844, passed resolutions urging brothers to coöperate in removing the "foul blot."

In the Old School, for several years past, memorials upon slavery had been laid on the table without comment. This action was, in 1844, strongly condemned by the Synod of Indiana, and the following year the General Assembly recognized memorials of three different characters, viz., those demanding amelioration of the condition of the slaves, those asking full discussion of the subject, and others demanding explicit declaration that slavery was a "heinous sin," and demanding exercise of discipline in the case of those practicing it. In answer to the latter, a report was accepted, by a vote of 164 to 12, which declared that "slavery could not be called necessarily a heinous sin without charging the apostles of Christ with conniving at a sin." By way of conciliation the Assembly added that they "would not deny there was evil connected with it." This action practically repealed such former testimony as that of 1818, and remonstrances came in from various quarters. The Presbytery of Beaver (Pennsylvania) declared themselves "aggrieved" at this justification of slavery, and the General Association of ministers in Massachusetts passed a resolution that a letter of remonstrance should be sent to the General Assembly. In 1846 the General Assembly declared that "after the action of 1818 and 1845 the Assembly need take no further action." The following amendment was proposed: "Except to say that the action of 1845 is not intended to deny or rescind the sentiments of the Assembly expressed at different times prior to this date." This was laid upon the table by a vote of 86 to 59.[1]

The New School General Assembly was flooded with memorials in 1846, receiving them from the Synods of Indiana, Ohio, and Cincinnati; from twenty-six Presbyteries and nine General Associations. The action was strongly anti-slavery, and though the Southern members voted in a body, a declaration of Dr. Duffield's was accepted by a vote of 89 *ayes*, 27 *noes*, and 4 *non liquet*. This report

[1] The same sentiment was, later, advanced in the form of a resolution, and carried without division.

declared the system to be "intrinsically unrighteous." "The testimony of the General Assembly from A. D. 1787 to 1818 inclusive has condemned it, and it remains still the recorded testimony, *from which we do not recede.*" It further exhorted all churches to put the evil from them, sympathized with the Southern churches "in their embarrassments," and finally resolved to leave the matter "with the Sessions, Presbyteries, and Synods."

Previous to this resolution the roll had been called for individual opinions, and this had almost exclusive attention for twelve Sessions. The arguments were mostly of a Scriptural character, and were conducted with less excitement than was expected. The majority of the demands were for "no action" or "compromise." General McAfee, of Kentucky, declared, "The body has no shadow of a right to touch this subject in the way of legislation;" and almost all the Southern members concurred in this sentiment.

From this time until the withdrawal of the Southern Synods in 1858, the anti-slavery party gained rapidly in strength in the New School. In the same year, owing to the increased agitation in regard to the Cherokee Mission,[1] the American Missionary Association was formed. Article VIII of the constitution declared: "This Society, in collecting funds, in appointing officers, agents, and missionaries, and in selecting fields of labor and conducting missionary work, will endeavor particularly to discountenance slavery by refusing to receive the known fruits of unrequited labor, or to welcome to its employment those who hold their fellow-beings as slaves."

The Old School continued to maintain its conservative policy. Many memorials were presented in 1845, but no action taken. In 1850 the General Assembly declared that its "previous and repeated declarations are such as to render any action unnecessary." In 1861 the Assembly referred all memorialists to its former testimony, and even in 1863, after withdrawal of the Southern Synods, the reaffirmation of the action of 1818, called for by the Presbytery of Illinois, met with a small opposing minority vote. In other words, the anti-slavery spirit now, in 1863, was not as strong as it had been in 1818, when the action was unanimous.

---

[1] For the "Relation of the American Board of Commissioners for Foreign Missions to Slavery," see pamphlet of that title, by Charles K. Whipple, Boston, 1861.

The clergy of the South were headed by Dr. Thomwell, "the Calhoun of the Church," and had decided upon secession during the winter of 1861. Dr. Thomwell's influence extended much outside of the Church, and in November, 1860, he had declared in a sermon that the political secession of the South had become "not only a right but a bounden duty." The Synods of the seceded States now organized as the General Assembly of the Confederate States of America.

In the Methodist Church the subject of slavery was again agitated about 1830–32, when the attacks upon the Colonization Society marked the opening of the more violent struggle. In 1832 the "Doctrine and Discipline" was again published, and the changes made since the edition of 1804 are indicative of the general pro-slavery movement in the Church. The beginning of the new anti-slavery movement was greatly retarded by the action of the bishops, who refused to put motions of an anti-slavery character that were offered in the Annual and Quarterly Meetings. They even went further, and in numerous cases those of the travelling ministry who expressed anti-slavery sentiments were tried and degraded from office.[1]

There was, however, no very public or concerted action until 1835, when a number of the members of the New England and New Hampshire Conferences issued an anti-slavery appeal which created a great deal of excitement.[2] It was immediately answered in a "counter appeal" by Rev. Wilbur Fiske, president of Wesleyan University, and for the succeeding months articles were exchanged regularly in *Zion's Herald*, Rev. Orange Scott appearing as a principal champion of the anti-slavery side.

This controversy greatly stimulated the formation of anti-slavery societies among Methodists, and led to the publication of an anti-slavery paper, *Zion's Watchman*, the first number of which appeared in January, 1836. It also influenced many Conferences to elect anti-slavery delegates to the coming General Conference. This, however, met in Cincinnati with strong pro-slavery sympathies. Almost its

[1] These were: George Storrs, Samuel Norris, La Roy Sunderland, Lucius C. Matlack, and about twenty others mentioned in "History of American Slavery and Methodism," by Lucius Matlack, Boston, 1848, p. 240.

[2] They had organized as a Methodist Anti-Slavery Society in 1833. The article was written by La Roy Sunderland, afterwards editor of *Zion's Watchman*.

first action was to refuse to publish an address from the Methodist Wesleyan Conference of England, in which the anti-Christian character of slavery was affirmed. Moreover, the Conference censured two of its members, who had attended anti-slavery meetings, by an overwhelming majority. It declared its disapprobation in the most "unqualified sense," and further resolved "that the Conference disclaim any right, wish, or intention to interfere in the civil and political relations between master and slave, in the slaveholding States of this Union." Rev. Mr. Smith, of Virginia, in offering an amendment that the names of the offending brethren should be mentioned in the resolution, said, "Let them be brought forth in all the length and breadth of their damning iniquity." This amendment, however, was lost. Only eleven members voted against the passage of the censure itself, and when Mr. Storrs moved that these names should be entered on the journal, his motion was immediately killed by being laid on the table. During the debates the greatest warmth was shown. After some particularly harsh epithets of Mr. Smith, Rev. O. Scott rose to his feet and demanded if the speaker had any allusion to him. Turning towards him, Mr. Smith said: "I have no more to do with that brother than if he did not exist. I wish to God he were in heaven!" — which is, as the reporter of the New York *Observer* intimated, a clerical expression for wishing him in the other place.

Rev. William Winans, of Mississippi, declared in a speech: "It is important to the interests of slaves that, in view of the question of slavery, there should be Christians who are slaveholders. Christian ministers should be slaveholders, and diffused throughout the Union. Yes, sir; Presbyterians, Baptists, Methodists, should be slaveholders. Yes; there should be members, and deacons, and elders, and bishops too, who are slaveholders." He declared that he himself had become a slaveholder "on principle."

As a result of such action in the General Conference, the local action was very diverse. The New York Annual Conference especially indorsed the pastoral "Advice" which had condemned giving countenance to *Zion's Watchman.* The Georgia Annual Conference resolved that "slavery is not a moral evil," and that the "dignified course pursued by our bishops in suppressing the attempts that have been made by individuals has the approbation and profound respect of this Conference." The Baltimore Conference resolved "that the

General Rule concerning slaves be so construed to make guilt or innocence depend upon attendant cruelty, and not upon the simple fact of purchase or sale." The South Carolina Conference declared that slavery was "not a proper subject for Church action, but exclusively appropriate to civil authority." The Kentucky Annual Conference declared unanimously against interference with the subject, but commended the rectitude and policy of the Colonization Society. In the New Hampshire Conference, on the contrary, resolutions were passed expressing approbation of the acts of its two members[1] who had been censured by the General Conference. The English address which had been refused publication in the General Conference was now answered by a body of ministers, who declared that out of the three thousand travelling ministers in the connection there were probably not three hundred who would admit the holding of slaves to be a sin against God.

In 1837, October 25, a Methodist convention was held in New England, and here the question of bishops' rights was discussed at length. This led to a lengthy controversy between Bishop Hedding and Dr. Fiske on the one side, and Orange Scott and Luther Lee on the other, which was carried on through the papers — six letters by Dr. Fiske appearing in the *Christian Advocate* of New York. The bishops had for a long time been accustomed to declare what business was a proper subject for the attention of Conferences, and a great deal of the anti-slavery agitation now took the form of protestation against their right to do so. In order to quiet this, the New England Conference, June 6, 1838, proposed its "Plan of Pacification," which caused rejoicing throughout the South; it was, in fact, a compromise with every point in favor of the slaveholder, and was frustrated by the action of certain abolitionist Conferences. The Maine Annual Conference was the only Northern body which officially indorsed it.

The year 1839 marks the beginning of individual secessions — first in Michigan, where Rev. W. W. Crane led the movement; others took place at Cleveland, Ohio, and at Munroe in the same State. The abolitionists also gained ground in the General Conference of 1840. Two or three Conferences besides those of New England

[1] George Storrs and Samuel Norris.

elected anti-slavery delegates, and abolitionist petitions were sent from four Conferences and over twenty individuals. The first of the latter was presented by Orange Scott. Great efforts were made at this session to secure the addition of "slaveholding" to the forbidden sins of the Discipline, but when finally put to the vote the motion was lost. The Conference further declared that it had no authority to expound rules of discipline, and "that it is the will of the General Conference that Annual Conferences adhere to the law of the Discipline as it now stands." The most pro-slavery action that was taken was, however, the declaration against the admission of colored testimony against white members. Cases of proscription for anti-slavery opinions were now becoming more and more frequent, as well as the number of individual secessions. The first organized secession took place in Michigan, February, 1841, where, in Wayne County five classes numbering eighty members cut loose, and on May 13 organized as "Wesleyan Methodists." They were soon joined by other small classes of deserters. Another considerable secession took place October 20, 1842, in Western Pennsylvania, under J. P. Betker and others. In November of this year *The Wesleyan* appeared, edited by J. Horton and O. Scott, and on the first page they announced their withdrawal. This was a signal for secession all over the country. Two whole churches seceded with Luther Lee in Providence, and others at Carthagena, and Exeter, New Hampshire. There were secessions at five different points in Ohio, at three in New York, two in Pennsylvania, one in Iowa, and others in many of the New England towns. A convention was held at Utica on the last day of May, 1843, and the Wesleyan Methodist Church organized with about six thousand members. Prohibition of slavery was added to the Articles of Religion, and the powers of bishops were much limited.

Owing to the frequency of secession the pro-slavery faction felt the need of strengthening their position. Dr. Fiske, of Wesleyan University, had been elected a bishop, but had resigned; in electing a successor the South urged the addition of one or two more. The North, however, had the majority, and decided it inexpedient to elect any at all.

Another grievance of the South was the decision in the case of Rev. F. A. Harding. The Baltimore Conference, in which he was a

minister, had declared him suspended from the ministry[1] until he should manumit certain slaves which he had acquired by marriage. This he protested he could not do, in virtue of the laws of the State, and appealed to the General Conference, where the decision was sustained by a vote of 117 to 56.[2] In the course of the proceedings Bishop Andrew announced that he also was possessed of slaves, and a preamble and resolution were offered by A. Griffith and J. A. Davis "that he desist from all exercise of his office so long as the impediment exist." The other bishops — Soule, Hedding, Waugh, and Morris — were unanimous against this action, but a motion "that this be considered advisory only" was laid on the table and the resolution carried. The Southern members presented a declaration, on the next day, that further union was inconsistent with success of the ministry in the South, and a committee was instructed to draw up a plan of friendly division. This was presented on June 3, but laid on the table. Hopes were still entertained of preventing division, and the decision in Bishop Andrew's case was set at naught by Bishop Soule, who publicly invited the former to preside at least at one Conference. These conciliatory measures, however, came too late, and a convention of the Southern delegates was called at Louisville, May 1, 1845. This body organized the Annual Conferences represented into the "Methodist Episcopal Church South," to hold its first General Conference at Petersburg, Virginia, May 1, 1846.

The greatest bitterness now arose between the two sections on account of the refusal of the North to give up any part of the Book Concern and Chartered Funds as was provided by the Conference of 1844.

As in the Presbyterian churches after the split into New and Old Schools, the Northern division continued its conservative policy in hopes of attracting the border churches, but with even less success. There was a slight attempt, in 1856, to add the sin of slaveholding to those prohibited in the Discipline, but this failed, while in the Church South the laws against buying and selling slaves which up to this time had been existing, were immediately expunged.

In the Baptist denomination agitation took place chiefly in the

[1] May 18. [2] May 22.

missionary societies. The English Baptists had sent letters to the Baptist General Convention, which refused to publish them. Another was unrecognized by the Board, but answered by an individual member, saying that the Board would not intermeddle. English abolitionists, coming over here with anti-slavery intentions, were led to refrain from public speaking for fear of alienating the whole Church.[1] In 1841 Rev. Jonathan Davis, a Georgia Baptist visiting Boston, boasted publicly from the pulpit that he owned thirty slaves, and would "wade knee deep in blood to defend his right to hold them." He wrote home that but very few of the one hundred and fifty-six Baptist clergymen in and around Boston were abolitionists. Finally in 1840[2] a convention was held in New York "for the purpose of considering the connection of the denomination with slavery and inquiring what could be done." The result was the formation of the National Baptist Anti-Slavery Convention. The Triennial Convention of 1841 aggravated matters by a pro-slavery compromise, and in 1843 many members withdrew from the missionary societies and organized the American Baptist Free Missionary Society at Boston. There was strong agitation now in the old boards to refuse contributions from slaveholders and to cease the appointment of them as missionaries. In 1844 the Alabama State Convention demanded "distinct and explicit avowal that slaveholders are eligible and entitled equally with non-slaveholders to all the privileges and immunities of the Society." Receiving a reply in the negative, they withdrew and organized at Augusta, Georgia, as the Southern Baptist Convention, electing a Board of Foreign Missions with its seat at Richmond.[3]

The Protestant Episcopal Church was probably fully as pro-slavery in spirit as the other denominations, but by careful avoidance of the subject in the discussions at the General Convention, they were able to maintain church union until the political secession had taken place, when a meeting of the two divisions became no longer practicable. That the pro-slavery spirit was strong is clearly evinced by this very silence; for, otherwise, the well-known fact that clergy and even bishops in the South were slaveholders could not have been overlooked.

---

[1] 1836. [2] April 28. [3] May 8, 1845.

Their theological seminaries were carefully closed against colored students, the first case of rejection being that of Mr. De Grasse in 1836, who had petitioned the General Theological Seminary. Three years later Bishop Onderdonk recommended a colored student, Alexander Crummel, and he also was refused admittance by the board of trustees. The bishop's recommendation was coupled with the clause, "if you shall think it right and proper to admit a colored member." Colored clergymen were, moreover, excluded from the conventions in New York and Pennsylvania at least, and the latter diocese had an express canon to that effect.

This same spirit is further evidenced by the voice of the Church papers. *The Churchman*, which has always been the most authoritative Episcopal sheet, denied the "right of slaves to read the Scriptures," in set terms. The *Spirit of Missions* gave much room to similar sentiments. Seven pages were given, in one instance, to a scheme of Mr. John McDonough, who, by working his slaves four extra hours each day, was enabled at the end of *only fifteen years* to set them at liberty, finding himself so much the gainer at the expiration of that period that he could purchase twice as many more. The Bishop of Georgia was so delighted with this scheme that he immediately proposed the establishment of a mission school to be placed under the charge of Bishop Polk, and the first expense to be met by gains from a large plantation run on the above benevolent principles. This school was to be named the McDonough Institute, after the philanthropist who had made the great discovery.

Such opinions as the foregoing were so prevalent that the harmony in the Church was undisturbed even by the capture of John Brown, which took place during session of the General Convention of 1859. "The good feeling between churchmen of the North and South occasioned mutual rejoicing."

For a year the condition of the Church was practically the same, the only change being that seven Southern dioceses no longer prayed for the President and Congress.[1] Not until 1862 did the Church divide, and then, as a matter of course, eleven States sent no delegates, these Southern members meeting in Georgia, as the "First Regular Council of the Protestant Episcopal Church in the

[1] It was for this reason that, at a later date, General Butler sent three Episcopal clergymen North as prisoners of war.

Confederate States." The following is extracted from their pastoral letter: "The Constitution of the Protestant Episcopal Church in the Confederate States, under which we have been exercising our legislative functions, is the same as that of the Church from which we have been providentially separated, save that we have introduced into it a germ of expansion which was wanting in the old constitution. The time has come when the Church should press more urgently than she has hitherto done upon her laity the solemn fact that the slaves of the South are not merely so much property, but are a sacred trust committed to us as a people to be prepared for the work which God may have for them to do in the future; to give back to them religious and moral instruction," etc. "It is also our obligation not to violate the sacred relations which God has created, and which man cannot consistently with church duty annul. We rejoice to be enabled to say that the public sentiment is rapidly becoming sound upon this subject, and that the Legislatures of several of the Confederate States have already taken steps towards their consummation. Hitherto we have been hindered by the pressure of abolitionism; now that we have thrown off from us that hateful and infidel pestilence, we should prove to the world that we are faithful to our trust."

As to the smaller sects and independent congregations which have from time to time, and so numerously, cut loose from the larger denominations, the records are, for the most part, inaccessible. It is reasonable to suppose their histories miniatures of those outlined in the foregoing pages. I subjoin extracts from the minutes of the General Convention of the "Christian Church," held at Marion, New York, October, 1850:

"*Resolved*, that we consider the personal freedom of every human being to be a sacred right of his nature; and that slavery, therefore, in this country and in every other, is a great infraction of the right of humanity; that it is not a natural relation; and that we entertain the belief and cherish the hope that the tendency of improvement, inseparable from the nature of man, and the teachings and spirit of the Christian religion, with the beneficent workings of the great Providence which tenderly cares for the welfare of each and all of God's moral offsprings, will finally abolish this relation from the face of the earth.

"*Resolved*, that to remove the evils of slavery it should be approached with no partisan motive; that the love of humanity, rendered wise by consciousness of the past imperfect state of all human society, should temper every word we write or utter on this subject; that we consider no part of the Union as being justified in boasting, regarding the fraternal ties which unite the different parts of our country together, an exclusiveness from sin over another; and that, forever, we ought to treat with kindness and esteem the good men and women of the South whose birth and education have providentially cast them in a region of country inheriting the system of slavery."

In a general survey of the period under consideration, one is struck by the similarity of the results brought about in the religious denominations and political parties by slavery, the fundamental cause underlying the great social revolutions of the times.

After the confusion of the Revolutionary War had subsided, and comparative order had taken its place, political parties became defined upon broad party principles, and their growth was one of steady individuation. In the same way the religious denominations gained a national organization, and each settled into its social and doctrinal rut. These lines of demarcation were, however, soon overshadowed by the unparalleled growth of slavery, which resulted first in the separation in the churches, then in the political disintegration of parties, and finally in the division of the Union itself.

It is astounding that an institution so evidently opposed to all ideas of moral justice should have found its warmest and staunchest supporters in the ranks of prominent churchmen. Such being the case, it is perhaps not so surprising that complete separations should have taken place in the churches sooner than in the political parties; that the moral convictions of anti-slavery ministers should have first rebelled against the compromises prompted by the ideas of political expediency prevalent among party leaders.

Bibliographical List of Authorities Consulted.[1]

SOCIETY OF FRIENDS.

Correspondence between James G. Birney, of Kentucky, and Several Individuals of the Society of Friends. *Haverville*, 1835.

A Testimony against that Anti-Christian Practice of Making Slaves of Men; by Elihu Coleman. *New Bedford*, 1733.

A Brief Statement of the Rise and Progress of the Testimony of the Religious Society of Friends against Slavery and the Slave Trade. *Philadelphia*, 1843.

Note: Chronological account of the action of the various Yearly Meetings.

Germantown Friends' Protest against Slavery, 1688. Artotype (fac-simile); by J. Carbutt. *Philadelphia.*

The Society of Friends in the Nineteenth Century: a Historical View of the Successive Convulsions and Schisms therein during that Period; by Wm. Hodgron. Smith, English & Co, *Philadelphia*, 1876.

An Address to Our Fellow Members of the Religious Society of Friends, on the Subject of Slavery and the Slave Trade in the Western World; by the Philadelphia Free Produce Association of Friends. *Philadelphia*, 1849.

An Address to the Quarterly, Monthly, and Preparatory Meetings and the Members thereof, composing the Yearly Meeting of Friends held in Philadelphia; by the Committee appointed at the late Yearly Meeting to have Charge of the Subject of Slavery. Printed by John Richards, *Philadelphia*, 1839.

Statistics of the Operations of the Executive Board of Friends Association of Philadelphia and its Vicinity for the Relief of Colored Freedmen, as presented to a Public Meeting of Friends held at Arch Street Meeting House. *Philadelphia*, 1st Month, 19th, 1864.

An Appeal to the Professors of Christianity in the Southern States and Elsewhere, on the Subject of Slavery; by the Representatives of the Yearly Meeting of Friends for New England. Knowles & Vose, *Providence, R. I.*, 1842.

Indiana: a Redemption from Slavery; by J. P. Dunn, Jr. American Commonwealth Series, *Boston*, 1888.

Society of Friends in the United States. Their Views of the Anti-Slavery Question and Treatment of the People of Color. Compiled from Original Correspondence. *Darlington*, 1840.

An Address from the Convention of American Women to the Society of Friends on the Subject of Slavery. *Philadelphia*, 1840.

PRESBYTERIANS AND CONGREGATIONALISTS.

A reply to Professor Tayler Lewis' Review of Rev. Henry Van Dyke's Sermon on Biblical Slavery; by Holmes Agnew. D. Appleton & Co., *New York*, 1861.

The Oberlin Jubilee, 1833–83. Edited by Professor W. G. Ballantine, *Oberlin*, 1883.

The Church and Slavery; by Albert Barnes. Parry & McMillan, *Philadelphia*, 1857.

Note: Strongly prejudiced in favor of the New School.

Man Stealing and Slavery Denounced by the Presbyterian and Methodist Churches; by Rev. Geo. Bourne. Garrison & Knapp, *Boston*, 1834.

---

[1] Authorities which treat, to any considerable extent, of more than one denomination are placed under the general heading, "Miscellaneous."

Slavery; by Wm. E. Channing. James Munroe & Co., *Boston*, 1835.

Remarks upon Slavery and the Slave Trade addressed to Hon. Henry Clay, 1839; by a Slaveholder.

A Review of the Rev. Moses Stuart's Pamphlet on Slavery, entitled "Conscience and the Constitution;" by Rufus Clarke, A.M., Pastor of North Church, Portsmouth, N. H. Originally published by the Boston Daily Atlas. C. C. P. Moody, *Boston*, 1850.

Details of a Plan for the Moral Improvement of Negroes on Plantations: Read before the Georgia Presbytery. Thos. S. Clay, 1833.

The Injustice and Impolicy of the Slave-trade and of the Slavery of the Africans, illustrated in a Sermon Preached before the Connecticut Society for the Promotion of Freedom and for the Relief of Persons unlawfully held in Bondage, in their Annual Meeting held in New Haven, September 15, 1791; by Jonathan Edwards, D.D., Pastor of a Church in New Haven. Printed by Thos. and Sam'l Green, 1791.

Oberlin, its Progress and Results. An Address Prepared for the Alumni of Oberlin College, Assembled August 22, 1860; by President J. H. Fairchild. *Oberlin*, 1871.

Historical Sketch of Oberlin College; by Rev. E. H. Fairchild. *Oberlin*, 1868.

An Address to the Presbyterian Church Enforcing the Duty of Excluding All Slaveholders from the Communion of Saints. *New York*, 1833.

History of the Presbyterian Church in the United States of America; by E. H. Gillett. 1864.

Come-Outerism: the duty of Secession from a Corrupt Church; by Wm. Goodell.

The New England Christian Herald (started as Zion's Herald); S. W. Wilson and S. O. Wight, Editors.

The Constitutional History of the Presbyterian Church in the United States of America; by Charles Hodge, D.D. Philadelphia Board of Publications, 1851.

Minutes of the General Assembly of the Presbyterian Church. New School.

The New York Observer.

Letter Addressed to the Churches; by James G. Birney. *Mercer County, Kentucky*, Sept. 2, 1834.

Reply to Remarks of Rev. Moses Stuart, lately a Professor in the Theological Seminary at Andover, on Hon. John Jay, and an Examination of his Scriptural Exegesis Contained in his Recent Pamphlet entitled "Conscience and the Constitution;" by Wm. Jay. Printed by John A. Gray, *New York*, 1850.

On the Inhumanities of the Slave Trade and the Importance of Correcting it. A Sermon Delivered in the Second Congregational Church, Newport, R. I., Aug. 12, 1792; by Wm. Patten, A.M., of that Church. J. Carter, *Providence*, 1793.

Letters on American Slavery, Addressed to Mr. Thos. Rankin; by John Rankin. Isaac Knapp, *Boston*, 1838.

Report of the Committee on Slavery, to the Convention of Congregational Ministers of Massachusetts. Presented May 30, 1849. Printed, *Boston*, 1849.

NOTE: Good history of slavery and the slave trade in colonial times.

Lectures on Slavery, Delivered in the North Presbyterian Church, Chicago; by N. L. Rice, D.D. Daily Democrat Print, *Chicago*, 1860.

Oberlin Unmasked; by Delazon Smith. *Cleveland, Ohio*, 1837.

The Church and Slavery; by R. L. Stanton, D.D. Derby & Miller, *New York*, 1864.

Position of the Southern Church in Relation to Slavery, as Illustrated in a Letter of Dr. F. A. Ross to Rev. Albert Barnes, with an Introduction by a Constitutional Presbyterian. Printed by John A. Gray, *New York*, 1857.

Proceedings of the Convention of Ministers of Worcester County on the subject of Slavery, held at Worcester, Dec. 5 and 6, 1837, and Jan. 16, 1838. Massachusetts Spy Office, *Worcester*, 1838.

The Unanimous Remonstrance of the Fourth Congregational Church, Hartford, Connecticut, against the Policy of the American Tract Society on the Subject of Slavery. Foundry of Silas Andrews & Sons, *Hartford*, 1855.

Two Letters on the Subject of Slavery from the Presbytery of Chillicothe to the Churches under their Care. Printed by Whetstone & Buxter, *Cincinnati*, 1830.

A Tract. History and Doctrine of the Associate Reformed Church. Presbyterian Office, *Due West, South Carolina*, 1871.

The Character and Influence of Abolitionism. A Sermon preached in the First Presbyterian Church, Brooklyn, on Sabbath Evening, Dec. 9, 1860; by Rev. Henry Van Dyke, Pastor. D. Appleton & Co., *New York*, 1860.

Separation from Slavery. A Premium Essay; by Rev. Sam'l Wolcott. Published by the American Tract Society, *Boston*, 18(?).

METHODIST EPISCOPAL.

Bangs' History of the Methodist Episcopal Church. Carleton & Phillips, *New York*, 1853.

Letter to Governor Wright, of Indiana, upon the Connection of the Methodist Episcopal Church with the Subject of Slavery; by Henry Clay Dean.

A Dialogue between Do-Justice and Professing-Christian. Dedicated to the Respective and Collective Abolition Societies and all other Benevolent and Humane Philanthropists in America; by Freeborn Garretson, Minister of the Gospel. *Wilmington* (no date).

America and American Methodism; by the Rev. Frederick J. Jobson. *London*, 1857.

History of American Slavery and Methodism; by Lucius C. Matlack. Published Monthly, *Boston*, 1848.

NOTE: The most complete of all accounts. Eight numbers were issued.

Border Methodism and Border Slavery; by J. Mayland M'Carter, of the Philadelphia Conference. *Philadelphia*, 1858

Methodism and Slavery; by Rev. Geo. Bourne. Garrison & Knapp, *Boston*, 1834.

NOTE: This is a comparison of editions of 1804 and 1832 of a volume entitled Doctrine and Discipline of the Methodist Episcopal Church.

A Compendium of Methodism; by Rev. James Porter, D.D. Carlton & Porter, *New York*, 1851. 19th Edition.

The Ground of Secession from the Methodist Episcopal Church, or A Book for the Times. Being an Examination of her Connection with Slavery, and also of her form of Government; by Rev. O. Scott, Revised and Corrected. To which is added "Wesley upon Slavery." Published by C. Prindle, *New York*, 1848.

Concluding Portion of an Able Review of the Present Position of the Methodist Episcopal Church with regard to Slavery; by Rev. Edward Smith (no date).

The Methodist Church and Slavery; by Charles K. Whipple. Published by American Anti-Slavery Association, *New York*, 1859.

The Majority and Minority Reports of the Committee on Slavery at the General Conference of the Methodist Episcopal Church, held in Buffalo, 1860.

"Who are the Schismatics?" Appeal to the Ministers of the Methodist Episcopal Church against the Schism of the Anti-Abolitionists. Percy & Reed, Printers, *New York*, 1838.

BAPTISTS.

Baptists' Encyclopedia; edited by Wm. Cathcart, D.D. *Philadelphia*, 1883.

The Baptists in America; by Rev. F. A. Cox, D.D., LL.D., and Rev. J. Hoby, D.D. *New York*, 1836.

Rev. Dr. Richard Furman's Exposition of the Views of the Baptists, relative to the Colored Population of the United States, in a Communication to the Governor of South Carolina. *Charleston*, 1823.

The Free-will Baptist Quarterly.

A History of the Rise and Progress of the Baptists in Alabama; by Hosea Holcombe, Minister of the Gospel. *Philadelphia*, 1840.

Minutes of the Hancock (Maine) Baptist Association.

History of the Baptists in Maine; by Rev. Joshua Millet. *Portland*, 1845.

The Baptists and the National Centenary; edited by Lemuel Moss, D.D. American Baptist Publishing Co., *Philadelphia*, 1876.

Proceedings of the Fifth Triennial Meeting of the Baptist General Convention, held in New York, April, 1826. Lincoln & Edmonds, *Boston*, 1826.

History of the Rise and Progress of the Baptists in Virginia; by Robert Semple, Minister of the Gospel in King and Queen County, Virginia. *Richmond*, 1810.

The History of the Free-will Baptists for Half a Century; by Rev. J. D. Stewart.

NOTE: Embracing the years 1780–1830. A second volume which was intended was never prepared.

Notes on the Principles and Practices of Baptist Churches; by Francis Wayland. *New York*, 1856 (or 1857).

MISCELLANEOUS.

The American Church in the Disruption; by the Author of "The Church Cause and the Church Party," and "Two Years of Church Progress." Reprinted from the "Christian Remembrancer" for January, 1863. *London*, 1863.

Publications of the American Reform Tract and Book Society. *Cincinnati, Ohio.* Tracts Nos. 1, 2, 3, 5, and 40.

James G. Birney and his Times; by Wm. Birney. D. Appleton & Co., *New York*, 1890.

The American Churches, the Bulwarks of American Slavery; by an American.[1] Oliver Johnson, *Boston*, 1843.

American Slavery in its Moral and Political Aspects, comprehensively examined, etc., to which is subjoined an epitome of Ecclesiastical History, showing the Mutilated State of Modern Christianity; by James Brown. *Oswego*, 1840.

The American Church and the American Union; by Henry Caswall, M.A. Saunders, Otley & Co., *London*, 1861.

Caste and Slavery in the American Churches. Wiley & Putnam, *New York* and *London*, 1843.

The History of Kentucky: by the late Lewis Collins, Judge of Mason County Court. Revised and enlarged fourfold and brought down to the year 1874 by his son Rich. H. Collins, A.M., LL.D. Collins & Co., *Covington County, Kentucky*, 1878.

A Candid Appeal to the Citizens of the United States, proving that the doctrines advanced and the measures pursued by the Abolitionists relative to the Subject of Emancipation are inconsistent with the teachings and directions of the Bible, and that those clergymen engaged in the dissemination of their principles should be immediately dismissed by their respective Congregations as False Teachers; by Simon Clough, D.D., LL.D., Pastor of the Christian Society, Fall River, Mass. A. K. Berton, *New York*, 1834.

[1] James G. Birney.

Observations on American Slavery; by Russell Lant Carpenter, B.A. Ed. T. Whitfield, *London*, 1852.

"Cotton is King" and "Pro-Slavery Arguments," comprising writings of Hammond, Harper, Christy, Stringfellow, Hodge, Bledsoe, and Cartwright, on this important Subject; by E. N. Elliot, LL.D., President of Planters College, Mississippi. *Augusta, Ga.*, 1860. Pritchard, Abbott & Loomis, Publishers.

Thoughts on African Colonization, or an Important Exposition of the Doctrines, Principles, and Purposes of the American Colonization Society, together with Resolutions, Addresses, and Remonstrances of the People of Color; by Wm. Lloyd Garrison. Garrison & Knapp, *Boston*, 1832.

The Annual Reports of the Glasgow Emancipation Society.

Slavery and Anti-Slavery; by Wm. Goodell. Wm. Harned, *New York*, 1852.

The Independent, 1848–1861.

NOTE: A paper founded to defend Congregationalism against Presbyterianism, and to advocate anti-slavery opinions and measures.

Thoughts on the Duty of the Episcopal Church in relation to Slavery, being a speech delivered in the New York Anti-slavery Convention, February 12, 1839; by John Jay. Percy & Reed, Printers, *New York*, 1839.

The Martyr Age of the United States; by Harriet Martineau. *Boston*, 1839.

NOTE: First published in the Westminster Review.

Missionary Boards in relation to Slavery, Caste, and Polygamy. From the "American Missionary" Extra, May, 1854. Published by the American Missionary Association, *New York*, 1854.

Practical Considerations founded on the Scripture, relative to the Slave Population of South Carolina; by a South Carolinian. A. E. Miller, *Charleston*, 1823.

The Church as it is, or the Forlorn Hope of Slavery; by Parker Pillsbury. *Boston*, 1847.

The Abolition Cause Eventually Triumphant. A Sermon delivered before the Anti-Slavery Society of Haverhill, Mass., Aug., 1836; by David Root, of Dover, N. H. Gould & Newman, *Andover*, 1836.

The Extinguisher Extinguished, or David M. Reese, M.D., "Used Up;" by David Ruggles, a man of color. *New York*, 1834.

History of the United States under the Constitution; by James Schouler. Dodd, Mead & Co., *New York*, 1880.

The Sin of Slavery and its Remedy; by Elizur Wright, Jr., Professor of Mathematics and Natural Philosophy at Western Reserve College. *New York*, 1833.

South Carolina. Published by the State Board of Agriculture, *Charleston, S. C.*, 1883.

Christianity and Emancipation, or The Teachings and Influences of the Bible against Slavery; by Joseph P. Thompson, Pastor of Broadway Tabernacle Church. Ans. D. F. Randolph. *New York*, 1863.

Tracts of the New England Anti-Slavery Tract Association. *Boston.*

Colonization; a Tract issued by the American Anti-Slavery Society. *New York.*

Relation of the American Board of Commissioners for Foreign Missions to Slavery; by Chas. K. Whipple. R. F. Wallcut, *Boston*, 1861.

The Family Relation as affected by Slavery; by Chas. K. Whipple. *Boston*, Jan., 1858.

An Address to the Christians of All Denominations on the inconsistency of admitting Slaveholders to Communion and Church Membership. R. C. Atkinson, Printer, *Philadelphia*, 1831.

Religious Organizations and Slavery; by Rev. Wm. B. Brown, of Sandusky City. James M. Fitch, *Oberlin*, 1850.

Minutes of the Proceedings of a Convention of Delegates from the Abolition Societies established in different parts of the United States. Assembled at Philadelphia, Jan. 1, 1794. *Philadelphia*, 1794.

"Negro Slavery." An English Pamphlet's Attempt to Enlist Religion on the side of Colonial Slavery Exposed. Extracted from the Christian Observer, June, 1830. (Being a review of a pamphlet published by Ridgway.)

Appeal to the Churches in Behalf of Africa. Leavitt, Lord & Co., *New York*, 1834.

Remarks upon Slavery and the Slave Trade. Addressed to Hon. Henry Clay, 1839; by a Slaveholder.

Rise and Fall of the Slave Power; by Henry Wilson. 7th Edition. Houghton, Mifflin & Co., *Boston*, 1887.

NOTE: Chapter XLIX, Volume III, is devoted to the attitude of the Churches.

Minutes of the General Convention of the Christian Church, held at Marion, N.Y., Oct., 1850. *Philadelphia*, 1851.

THE PURIFICATION OF WATER BY METALLIC IRON.[1]

By EASTON DEVONSHIRE, Assoc. M. Inst. C. E.

Were any special proof needed to show how rapidly this country is arriving at the age of maturity, it might be found in the increased attention which is given, not only by scientific men and professional sanitarians, but by the people at large, to questions affecting public health. Of these questions, not the least important is that of the quality of the water we are to drink, and the precautions that should be taken to prevent this necessary of life from being a possible source of danger to the health of the consumer. In the phenomenally rapid growth of cities in this great country, sufficient attention has not been paid, in the first instance, to sanitary considerations, which have almost necessarily been postponed for want of time to give them the prominence they deserve. Again, the increase of population and the growth of industries of all kinds in the neighborhood of the waterways, which were the cause of their location, have altered the conditions which originally permitted, if they did not justify, the utilization of natural waters for the drinking supply of cities and towns. In the older countries of Europe, long since densely populated, it has for years past been found necessary to endeavor to counteract by artificial means the inevitable pollution of sources of water supply at one time deemed harmless. Also, the advancement of science has proved the dangers to public health which impure water offers, and which were, until comparatively recent times, but imperfectly recognized.

The oldest method of artificially improving impure water is that of filtration through sand. It is the general practice in England

[1] A lecture delivered before the Society of Arts, Massachusetts Institute of Technology, December 11, 1890.

and in many parts of the continent of Europe to submit water drawn from rivers, or other sources not entirely free from suspicion of contamination, to the process of sand filtration.

This process consists of allowing the water to percolate through a layer of sand two or more feet in thickness at a speed sufficiently slow to remove at least a considerable portion of the suspended impurities. The action of the sand filters, worked as they are in ordinary practice, is purely mechanical, the dissolved organic matter not being reduced in any important proportion. They are, however, capable, as has been shown by Piefke, of arresting bacteria to an extent which their porosity would not seem to render possible, the explanation being found in the formation, after several days' working, of a sticky film or membrane, which Piefke terms "bacteria jelly," to which the micro-organisms adhere when the speed at which the water passes through the sand bed is maintained at a slow and unvarying rate. This speed will differ according to the nature of the water and the standard of improvement aimed at. Under favorable conditions it should not exceed sixty gallons per square foot per day, while half this speed will fail to remove the color due to finely divided clay or peat so frequently met with in river and impounded surface waters.

In 1879, when a charter for the water supply of the city of Antwerp, in Belgium, was granted by the municipal authority to an English firm, permission was given to use the river Nethe as the source of supply, on condition that its water should be submitted to a careful filtration through sand before distribution.

Before commencing to construct the works, however, the proprietors foresaw that simple sand filtration would fail to remove the peaty color from the water and render it sufficiently attractive to the eye to compete with the old established supply obtained from the shallow wells with which each household was provided. It was recognized that whatever superiority the sand-filtered river water might be shown to possess over the contaminated well water, the commercial success of the undertaking would be endangered by the inferior appearance of the new supply. Several chemically acting filtering materials were known to be capable of removing the objectionable color, and, after an examination of the merits of each of

them, the material known as Bischof's spongy iron was selected. Successful experiments were made, and filters containing spongy iron were designed and constructed.

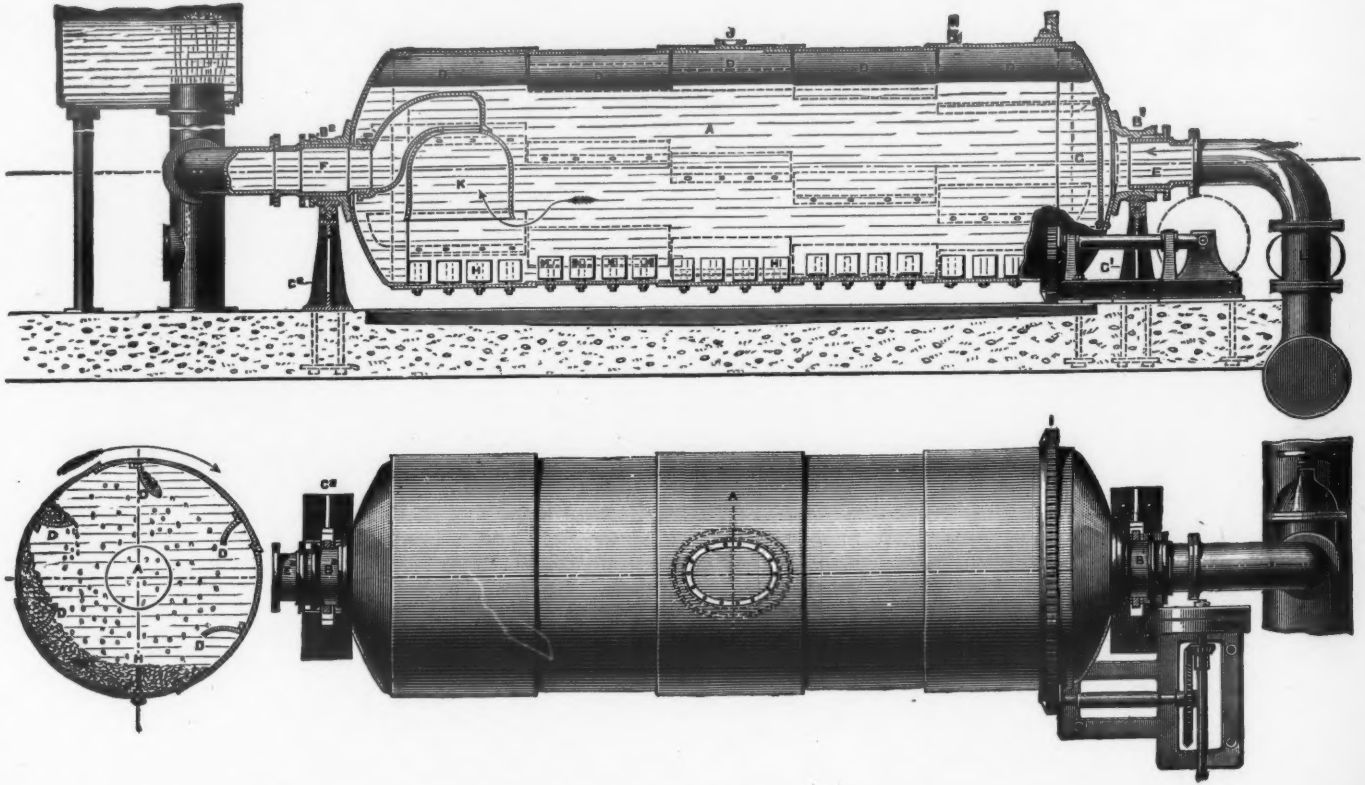
Spongy iron is obtained by roasting hematite ore to a point just short of fusion, the metal being rendered porous or spongy by this operation. Some nine hundred tons of this form of iron, mixed with three times its bulk of fine gravel, were used to form three filter beds. The river water percolating through these beds took up a portion of the metal, forming a ferrous salt, which by subsequent contact with the air was precipitated as ferric oxide, and acting as a coagulant, allowed the water to be strained through a bed of sand, and to issue bright and colorless.

The desired improvement in appearance was thus obtained, and at the same time the water was found to be purified to a remarkable degree. The Bischof process, though costly, thus promised to solve the problem how to utilize an impure natural water without danger to public health.

For nearly three years the Bischof filters realized expectations; but gradually, as the demands of the city increased, it was noticed that the daily delivery of the filters was decreasing in quantity. Investigation showed that the material was caking and rusting together, and was being clogged with the substance formed by its chemical action on the dissolved organic matter of the river water. Finally, when great expense had been incurred in efforts to maintain the porosity of the filters, William Anderson, the consulting engineer of the works, designed a method of overcoming the mechanical difficulties of filtration. This method, known as the revolving purifier system of purification, is the invention which my paper is to treat of tonight.

The somewhat long introduction I have given it is for the purpose of showing what was the necessity for the invention, and what were the difficulties in water purification and filtration it had to overcome.

In Bischof's, as in all other systems of chemically acting filters, the water is brought into contact with the purifying medium by percolating through it. Anderson reversed the principle by designing an apparatus in which the purifying medium is continuously showered down through a flowing stream of water. The apparatus by which the


A
D
D'
E
K
L
C'
C''
C'''
B
H

result is effected consists of a cylinder A, supported in a horizontal position by hollow trunnions B_1 B_2 revolving in pedestal bearings C_1 C_2, placed one at each of its extremities. Within the cylinder are a series of short curved shelves D D D, arranged in steps at equal distances round its circumference, and reaching from end to end. In the place of a sixth row of curved shelves is a line of small square plates H H H, which, by means of nuts outside the cylinder, can be set at an angle with the axis of the purifier. These plates serve to direct the shower of iron back towards the inlet end of the apparatus, and so to counteract the tendency of the current of water to carry the purifying material forward. Through the hollow trunnions, which are provided with stuffing boxes, pass the ends of inlet and outlet pipes E and F, which bring and which carry off the water to be purified. Facing the inlet pipe E is a circular distributing plate G, secured at a distance of ⅜ inch or ¾ inch from the end of the cylinder, serving to distribute the water radially on its entering the cylinder, and prevent its flowing into a direct current along the axis of the apparatus. The inner end of the outlet pipe is fitted with an inverted bell-mouth K, carried down as near to the bottom of the cylinder as the shelves will allow, and intended to prevent the finer particles of iron from being carried out by the current of water. A rotary motion is given to the cylinder through gearing working into an annular spur-wheel I, surrounding one end of the cylinder.

Through a suitable hand or manhole J, iron, in a moderately fine state of division, is introduced into the cylinder and spread evenly along the bottom in sufficient quantity to occupy one tenth of the capacity of the cylinder.

When the revolving purifier is to be set in motion, the sluice-cock L, provided at the inlet, is opened and the cylinder filled with water, the air being expelled through the air-cock M, which at that time must be at the top of the cylinder. When all the air is expelled the air-cock is shut, and the apparatus is set in motion by a small steam-engine, or other suitable form of motor, the speed of rotation being about six feet per minute at the periphery. By this rotary movement the shelves are successively caused to scoop up the iron granules, which at starting are spread evenly along the bottom of the cylinder, and to shower them down through the water.

By means of the sluice-cock L, the flow of water may be regulated to the speed required to give the duration of contact with the iron found necessary for efficient purification under the particular circumstances.

In his first experiments Anderson used spongy iron, which was up to that time supposed to possess special merit as an active purifier. Experiment, however, showed that scrap iron, in any convenient form, was equally active. The great difference in cost of the two materials of course made this discovery a valuable one.

The objections to the practical working of spongy iron filters on a large scale were twofold. First, the rusting together of the mass; and secondly, the coating of the material by the products of its own chemical activity, whereby the contact between the metal and the water was continually being impaired.

The revolving purifier obviates both of these objections; in the first instance by showering a small quantity of the material loosely through the water, and in the second by the automatic cleaning which each particle of the metal gets by rubbing against its neighbors.

The theory of the process is the formation, in the water passing through the purifier, of a protosalt of iron, through the solution of a minute portion of the metal by the carbonic acid and oxygen contained in the water. On issuing from the cylinder into the open air the protosalt is converted by further oxidation into the insoluble form of ferric oxide. In its formation the ferric oxide entangles the suspended matter and oxidizes the organic ingredients of the water. The destructive action of the ferric oxide on the organic matter has been described as being similar to that of rust stains or iron-mold on linen, the fibres of which are apparently burnt up.

Micro-organisms are at the same time caught and held in the precipitate. Dr. Edward Frankland goes farther, and considers that they are actually destroyed, the iron having a toxical effect. Whatever may be the true facts of the case, it has been proved by repeated analysis that the purification of the water is effected by the time the precipitate is completely formed. Subsequent sand filtration has only to remove the precipitate by mechanical straining.

Professor Kemna, of Antwerp, who has studied this process very fully, has expressed the opinion that the micro-organisms are to a great extent arrested by the film of oxide formed on the surface of the sand bed. I, at one time, expressed the same view; but recent

experiments lead me to think that, as far as the bacteria originally present in the water are concerned, the precipitate alone is capable of holding them. Of course in practical working the purified water receives continually a fresh supply of bacteria from the air. These are certainly removed during filtration; and here the coating of oxide, which the sand receives, is of great value, replacing the gelatinous film and the membrane formed by the growth of algæ on ordinary sand filters, as explained by Piefke in his experiments with the Berlin filters. It is also possible that the ferric oxide film on the sand removes the last trace of free ammonia, the entire absence of which is characteristic of the iron process.

Weekly analyses of the Antwerp water before and after filtration show that, in actual practice on a large scale, the albuminoid ammonia is reduced to one third of its original amount; free ammonia and nitrous acid entirely disappear, and nitrates are brought down to the smallest trace.

As regards micro-organisms, continued examinations by Koch's gelatine test show that, from the number of 50,000 to 100,000 in the river water at Antwerp, the highest figure during the whole of last year in the filtered water was twenty colonies per cubic centimetre, the average being only four or five colonies. This means practically the sterilization of the water. The figures are the more remarkable as they are the results obtained daily, under all conditions of the water, and in the fifth year of the uninterrupted working of the process.

The principle followed out in this process differs essentially, in one important respect, from that of the high pressure system of filtration which, in conjunction with the use of alum as a coagulant, has been the subject of many patents in this country.

With high pressure filters the coagulated impurities are strained out of the water while the latter is forced, at a high rate of speed, through a compressed bed of sand of comparatively small area. The effect of the high rate of speed is to impregnate the whole depth of the filtering materials with the coagulated impurities. At a given moment the filter is clogged up through its whole depth, and must be washed throughout by a reverse current before being used again. In Anderson's process care is taken so to regulate the speed of filtration that the sand bed shall be capable of retaining

at its surface the precipitate formed by the iron. In this way, as long as the filter maintains a specified delivery under a constant and low pressure, the certainty exists that the mass of the sand is absolutely unfouled, and water is obtained of the same degree of purity from first to last. Further, as a matter of economy slow-running filters have proved the best. Although of much greater area, the fact that they require cleaning only once in six weeks or two months, as against the daily washing given the high pressure filters, makes their working cost the lower of the two.

When the difference of cost of scrap iron and alum is taken into account, comparative statements of the working cost of the two processes show that for similar waters the iron process does not cost more than half the alum process.

From what may be called the sentimental point of view, the avoidance of the use of chemicals, whether alum or salts of iron, such as perchloride or sulphate of iron, is a strong argument in favor of the Anderson process for the treatment of potable waters.

The actual working cost of the revolving purifier process varies with the nature of the water treated, and may be considered as being more or less in proportion to the activity of the particular water in contact with the metal, and the readiness with which the precipitate forms. A clear water, free from mud and suspended impurities, is by no means necessarily the cheapest purified; for with waters like that of the Mississippi, containing an immense quantity of finely suspended clay as well as much easily separated mud, a few minutes' agitating with plate punchings produces such a coarse and voluminous precipitate that ninety per cent of it can be arrested by obstacles placed in the channel along which it runs on its way to the filter bed. On the other hand, a large quantity of organic matter of certain kinds will retard the precipitation of the iron, and keep the precipitate in a finely divided condition until the sand is reached. It is the finely divided matter, be it a precipitate of ferric oxide or suspended clay, which shortens the life of the filter. Thus, to go to an extreme case, clean sand carried mechanically in water can be strained out with the greatest facility without choking the filter. With the iron process, where a voluminous coarse precipitate is formed, the whole bulk of it may be sent on to a sand filter, and yet the life of the filter will be three or four times as long as with a fine precipitate of small volume.

The workings of the process at Antwerp and Dordrecht, in Holland, serve as excellent comparative illustrations of this. At Antwerp the water is charged with much organic matter, both vegetable and animal, but contains comparatively little finely suspended mud. Before the introduction of settling reservoirs the filters had to be scraped on the average once a fortnight. At Dordrecht, where the water is organically much purer, but holds a great deal of fine clay in suspension, the filters run for five weeks, although the water goes direct on to them from the purifier.

I stated before the Franklin Institute, some eight months ago, that for quantities of five million gallons per day and upwards the working cost of the process in no case would exceed two dollars per million. I have since received the figures of cost for the year 1889. Although on the average less than 750,000 gallons were pumped daily, this being under half the capacity of the plant, the 234 million gallons pumped in the year cost only $257, a fraction over one dollar per million. Of course with large volumes the cost per million decreases.

ONE MONTH'S WORK ON TWO PLANE-TABLES.

By ROBERT H. RICHARDS, Professor of Mining and Metallurgy, Massachusetts Institute of Technology.

The Summer School of Mines, which occurs on alternate years with that of Metallurgy, was held at Ishpeming, Michigan, in June, 1890. One of the chief features of these schools is the geological survey, which is so laid out as not only to give practice in surveying and in drawing geological sections, but also in the use of geological maps and sections as a means of predicting the whereabouts of new ore deposits.

The map here given was prepared from the surveys of the members of the Summer School of Mines, and has served in its execution to show how data must be collected, and how put together in order to be made available as a guide for the bounding of old and the search for new deposits.

A similar map made by the Summer School of 1888 has led to the discovery of a promising ore deposit previously unknown to the company.

The legend written upon the side of the map will be found to explain the main features and facts which the map brings to light.

One Month's work of two Plane Tables,

June 1890, on the geology of Ishpeming Michigan, by twelve mining students of the Massachusetts Institute of Technology; G. W. Faivor, E. L. Hamilton, F. H. Harvey, W. Haskins, F. H. Howland, H. G. Lobenstine W. Macgregor, H. C. Parkes, A. B. Payne Jr, H. E. Schroeter, J. R. Stevenson W. H. Weston, under the instruction of Robert H. Richards, Professor of Mining and Metallurgy.

Owing to the shortness of time available certain data, of necessity missing, have been assumed, they are:-

That the surface at Barnum shaft A is 22 feet below L. S. & Ma. Engine floor
That D.D. Hole N°11 " 22 ft " " " "
That Diamond Drill Hole N°142 " 57 " " " " "
that station T. " 25 " " " " "

Also the location of D.D.H. 16 obtained by angles to three reliable points is probably good, but why it is in La. S. & Co instead of J. C. Co's ground we have not ascertained, may be the E & W boundary line is wrongly placed. The boundaries were none of them located on the ground and are quite probably in Error. (Except the two meeting in N°3 shaft they were carefully located)

Also the line of strike of the rocks W. of Barnum B. shaft is assumed N. 74. W.

Facts are drawn in with hard lines and are, with the above exceptions, close to the truth. Geological speculations are put in with dotted lines.

The facts of most interest seem to be:-

1. Section E. F. shows a continuation eastward of the main fold of section A. B. While section G. H. fails to show a further continuation. The fold in A., pit is surely not the same as that in E. F. it clearly lies to the north of the latter, and no indication of it appears in any diamond drill hole further West.

2. D.D.Hs 8, & 142, do not encourage the hope that hard ore will be found in the region between them except near N°8.

3. D.D.Hs 8, 7, & 11, encourage the belief that a good body of hard ore lies between them, but this is unfortunately under the densest settled part of Ishpeming. These three holes also suggest that the ore under the town is in one great fold

4. If the synclinal suggested for section E. F. is right, there will undoubtedly be more or less hard ore down in the synclinal but it will presumably be much contorted and squeezed.

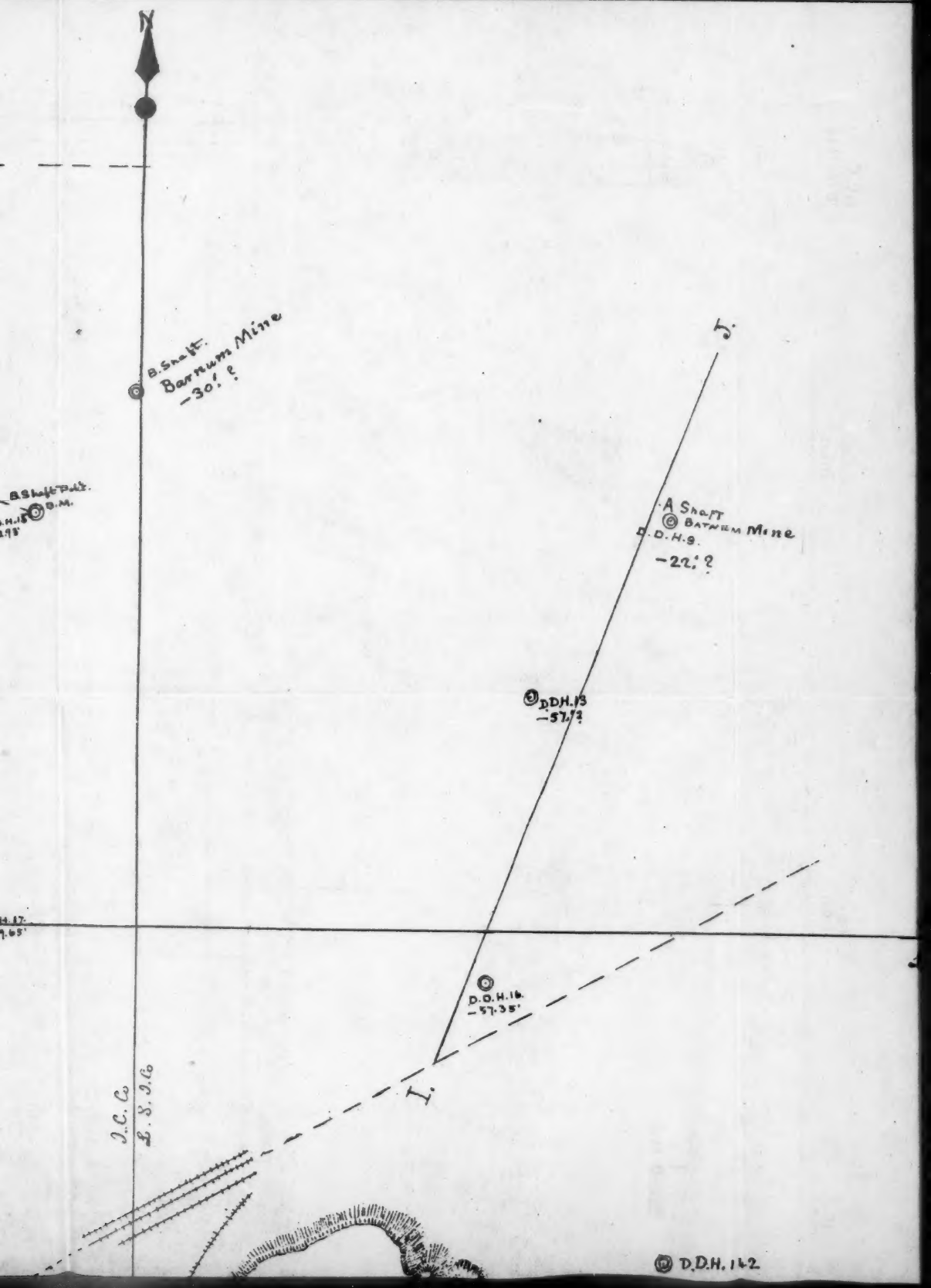
5. The relation of hard ore and hard ore jasper to hematite. (soft ore) and hematite jasper (soft ore jasper) is only indicated at one place namely in D D H 142.

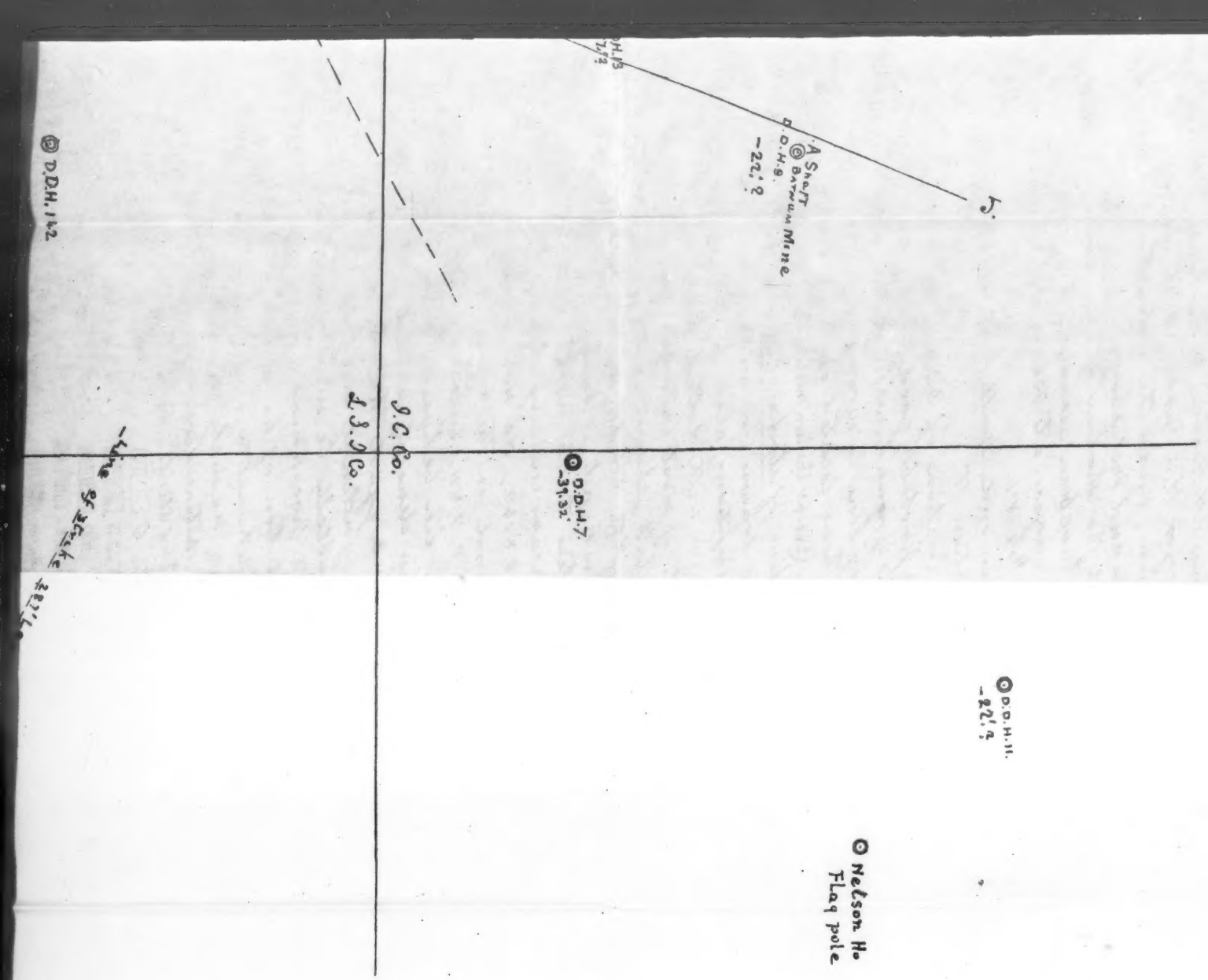
6. The two soapstone dikes N of section I. J. are the only nonconformable Schists on the N. & S. Bound.

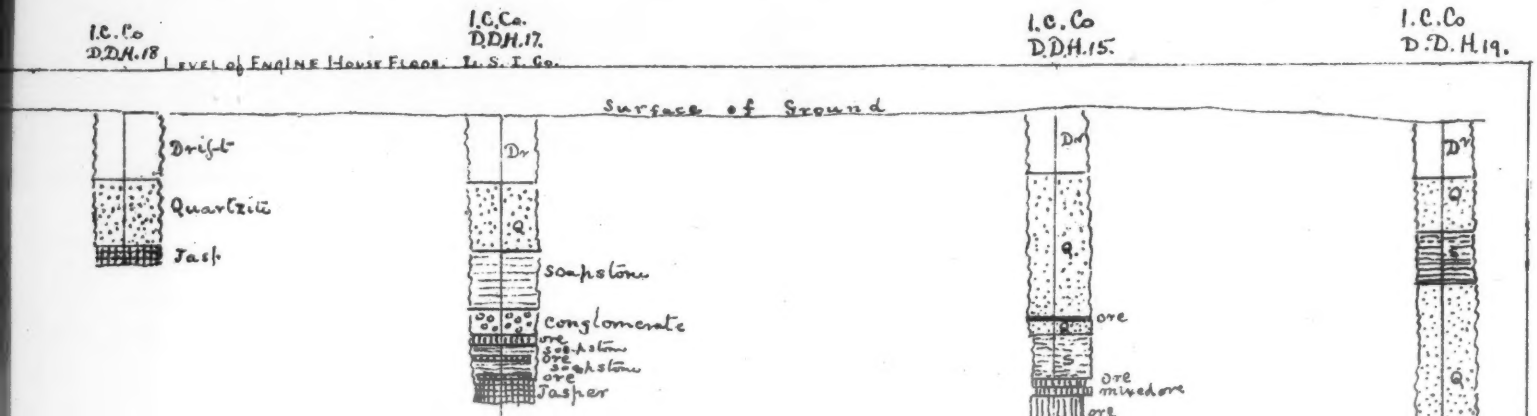
7. The order of strata seems to be:-

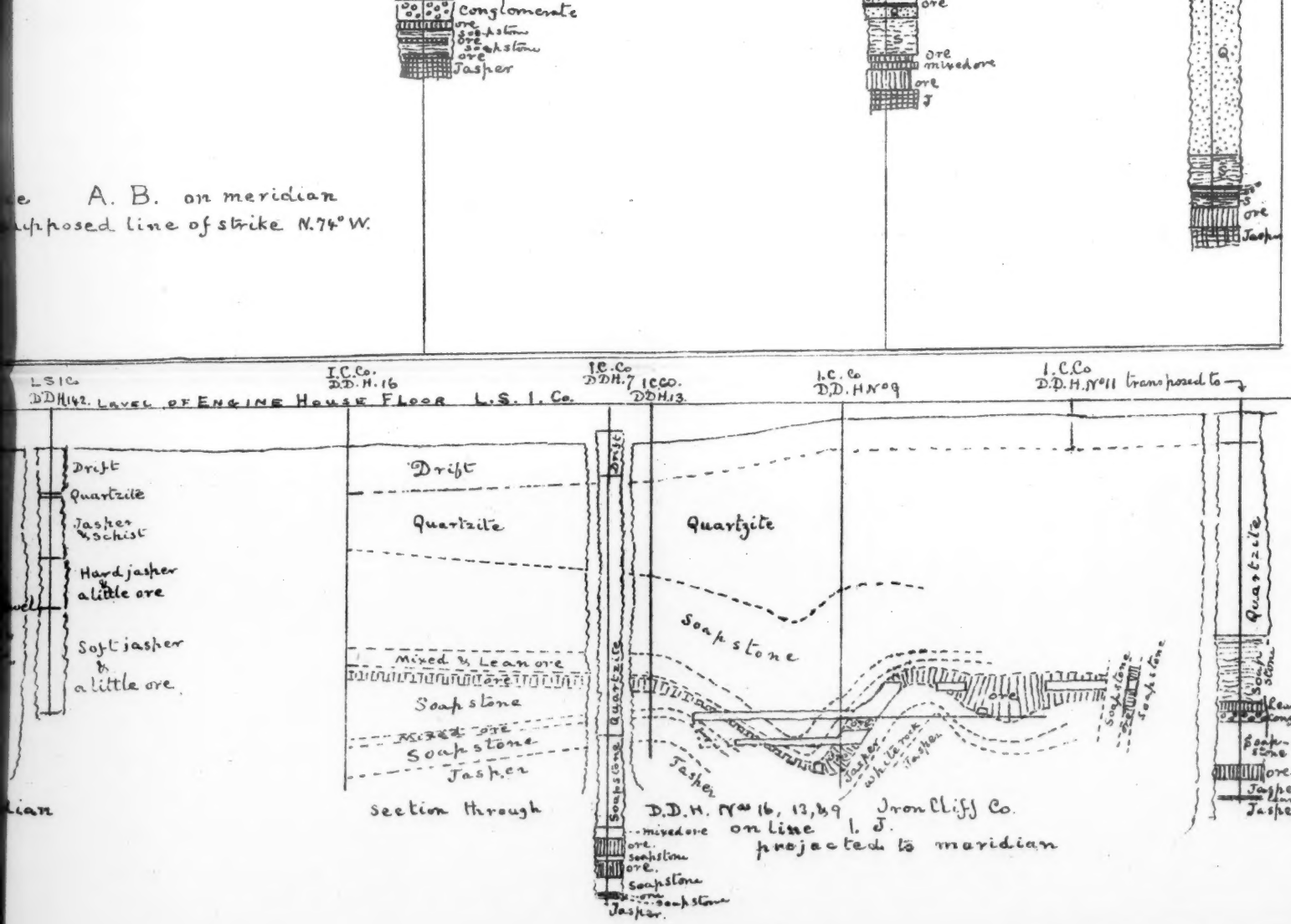
Quartzite Q
Schist or Soapstone S.
Hard ore H.O.
Hard ore jasper H.O.J.

These relations can be seen upon the map in every respect except the contact between the Lower schist and the diorite.


N
B. Shaft.
Barnum Mine
-30.' ?
A Shaft
BATNEM Mine
D.D.H.9.
-22.' ?
D.D.H.13
-57.7?
D.O.H.16.
-57.35'
I.
I.C.C.
L.S.I.C.
D.D.H.142


D.D.H. 142
A Shaft
D.D.H.9.
Barrow Mine
-22.'?
D.D.H.13
7.'?
I.C.Co.
I.C.Co.
D.D.H.7.
-39.32.
D.D.H.11.
-22.'?
Nelson Ho
Flag pole


I.C.Co
D.D.H.18
I.C.Co.
D.D.H.17.
I.C.Co
D.D.H.15.
I.C.Co
D.D.H.19.
Level of Engine House Floor. I. S. I. Co.
Surface of Ground
Drift
Quartzite
Jasp
Dr
Q.
soapstone
conglomerate
ore
soapstone
ore
soapstone
ore
Jasper
ore
ore
mixed ore
ore


Conglomerate
ore
Soapstone
ore
Soapstone
ore
Jasper
ore
mixed ore
ore
J
Q
S
ore
Jasper
A. B. on meridian
supposed line of strike N.74° W.
L.S.I.Co
D.D.H.142. LEVEL OF ENGINE HOUSE FLOOR L.S. I. Co.
I.C.Co.
D.D.H.16
I.C.Co
D.D.H.7
I.C.Co.
D.D.H.13
I.C.Co
D.D.H.N°9
I.C.Co
D.D.H.N°11 transposed to
Drift
Quartzite
Jasper & schist
Hard jasper & a little ore
Soft jasper & a little ore
Drift
Quartzite
Mixed & Lean ore
Soapstone
Mixed ore
Soapstone
Jasper
Drift
Soapstone
Quartzite
Soapstone
ore
Soapstone
ore
Soapstone
ore
Soapstone
Jasper
Quartzite
Soapstone
Jasper
Jasper
Jasper
Soapstone
Soapstone
Soapstone
ore
Jasper
Quartzite
Soapstone
Lean conglom.
Soapstone
ore
Jasper conglom.
Jasper
Section through
D.D.H. N°s 16, 13, 9 Iron Cliff Co.
on line I. J.
projected to meridian

but it will presumably be much contorted and squeezed.

5. The relation of hard ore and hard ore jasper to hematite. (Soft ore) and hematite jasper (soft ore jasper) is only indicated at one place namely in D D K 142.

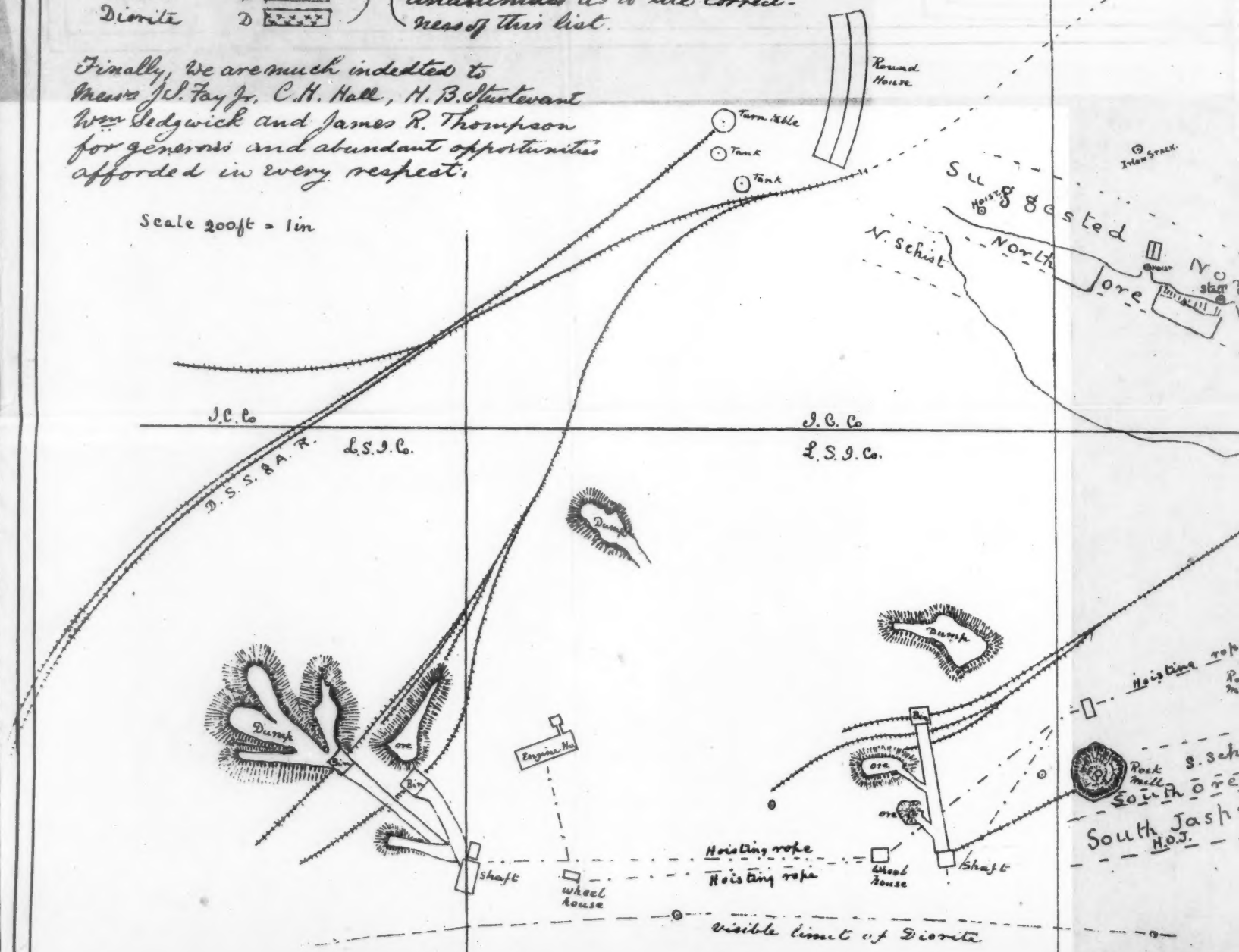
6. The two soapstone dikes N of section I.J. are the only nonconformable schists on the map Brand.

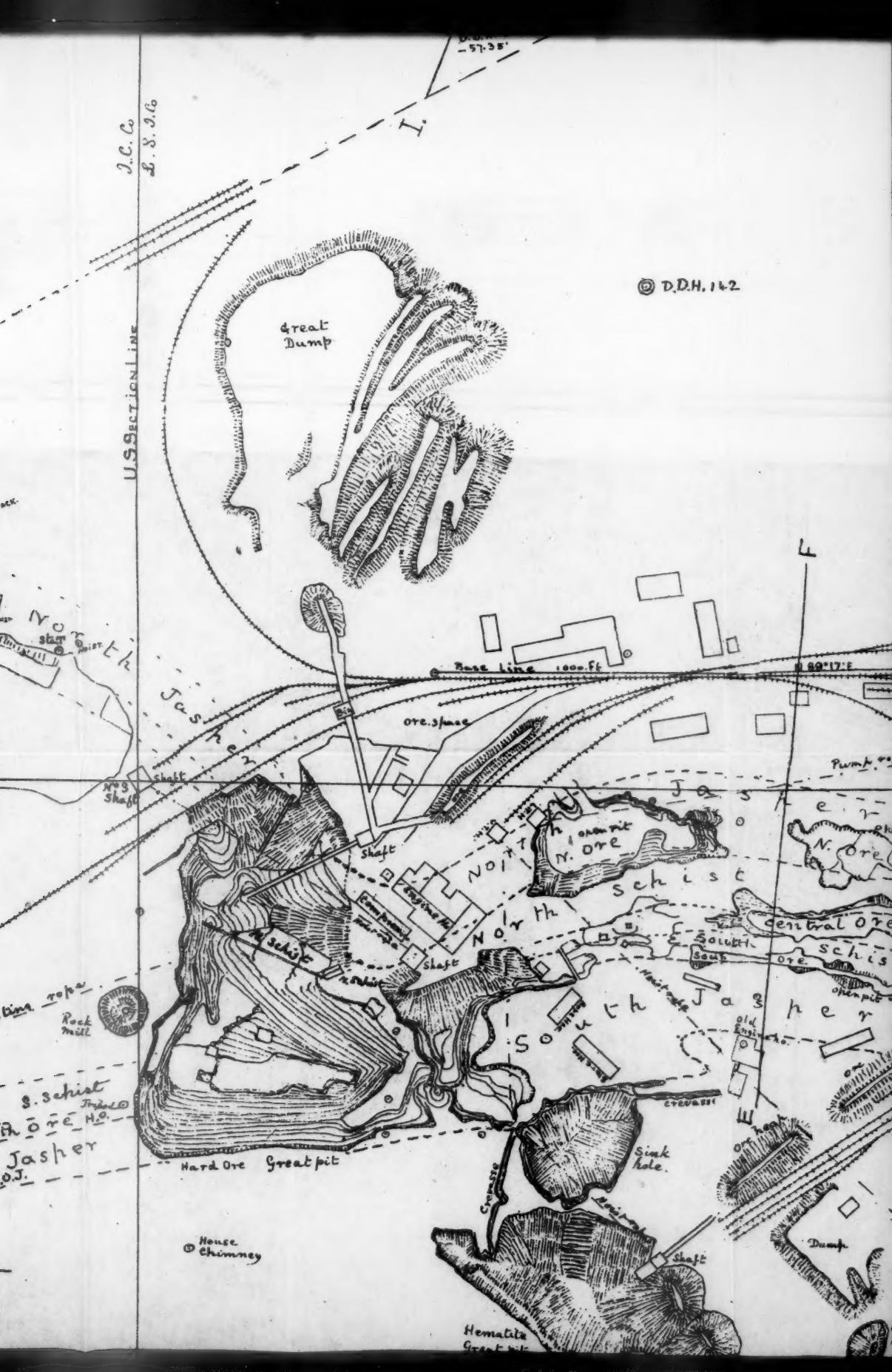
7. The order of strata seems to be:-

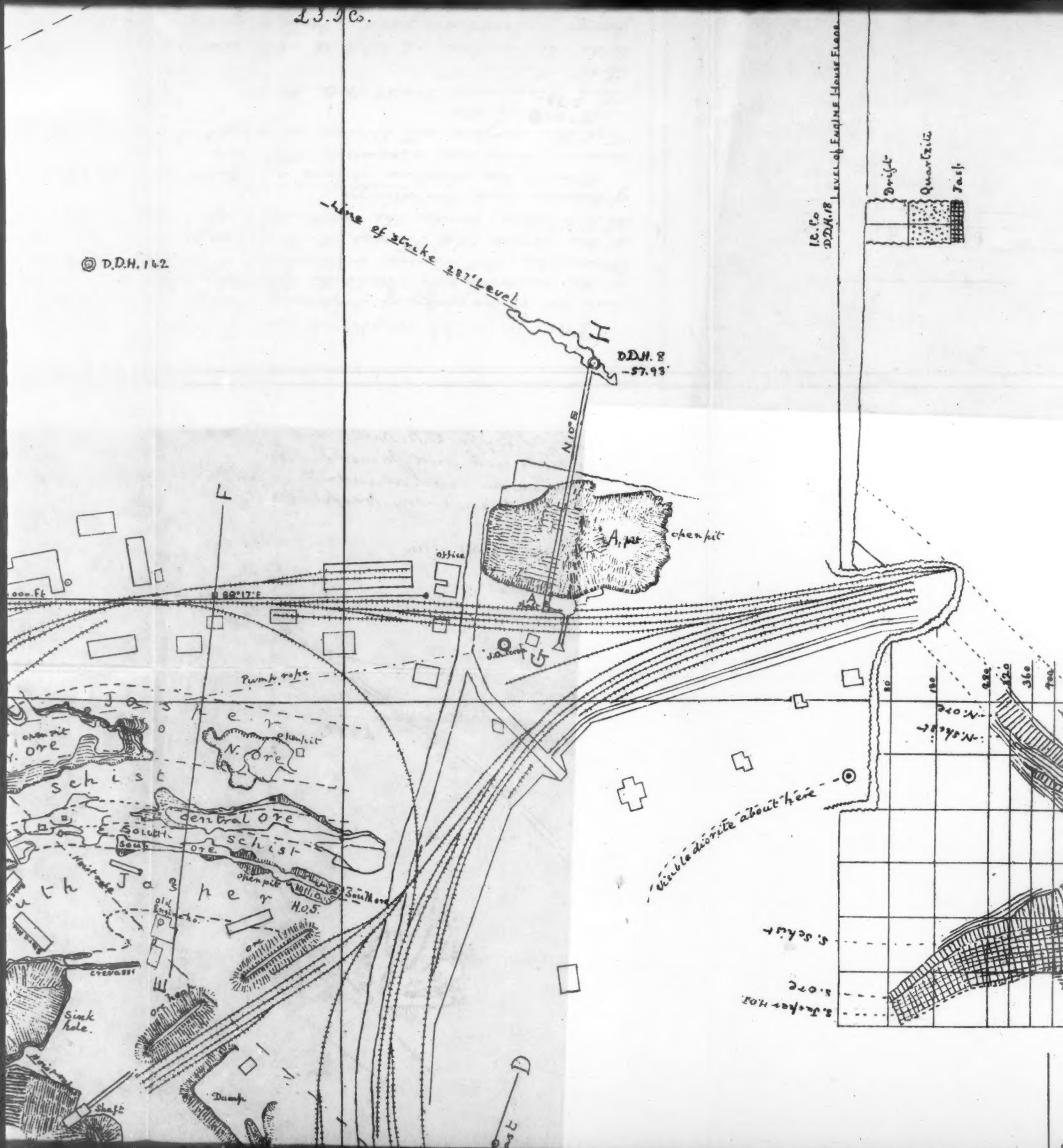
Quartzite	Q	These relations can be seen upon the map in every respect except the contact between the lower schist and the diorite. The mining men of Ishpeming as far as we have consulted them seem to be unanimous as to the correctness of this list.
Schist or Soapstone	S.	
Hard ore	H.O.	
Hard ore jasper	H.O.J.	
Hematite Jasper	S.O.J.	
Hematite	S.O.	
Schist	S	
Diorite	D	

Finally, we are much indebted to Messrs J.L. Fay Jr. C.H. Hall, H.B. Sturtevant Wm Sedgwick and James R. Thompson for generous and abundant opportunities afforded in every respect.

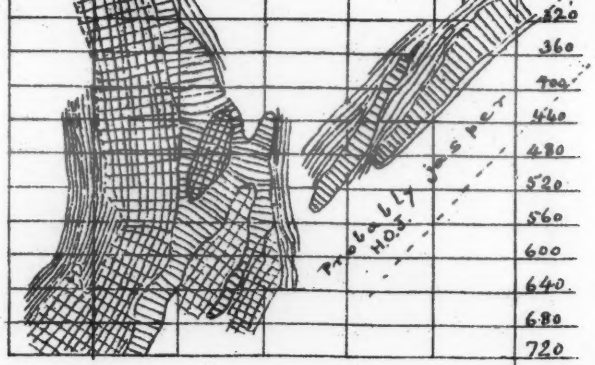
Scale 200ft = 1in



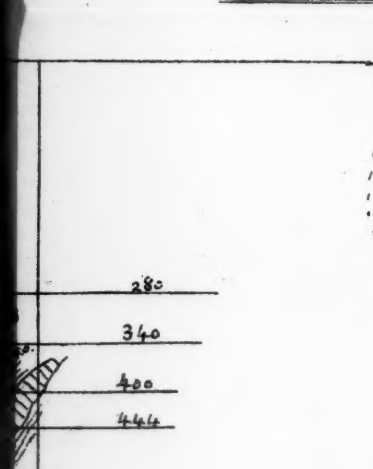

J.C.C.
L.S.J.C.
U.S. Section Line
D.D.H. 142
Great Dump
Base Line 1000 Ft
N 89°17' E
Ore Space
Shaft
No 3 Shaft
Pump
North Jasher
South Jasher
N. Ore
Central Ore
South Ore
Schist
Old Engine
Rock Mill
Hard Ore Great pit
Sink hole
Crevasse
House Chimney
Dump
Hematite Great pit


L.J.Co.
D.D.H. 142
Line of strike 287' Level
D.D.H. 8
-57.93'
N.10°E
L
H
D
E
G
A
A, pit
open pit
office
000. Ft
S 89°17' E
Pump rope
Jasper
ore
schist
N. ore
central ore
South ore
Jasper H.O.S.
old Engine ho.
Sink hole
Dump
Shaft
crevasse
L.J.Co
D.D.H.18
Level of Engine House Floor
Drift
Quartzite
Fault
Visible diorite about here
N. shaft
S. shaft
S. Jasper H.O.S.
S. ore
10
120
240
360

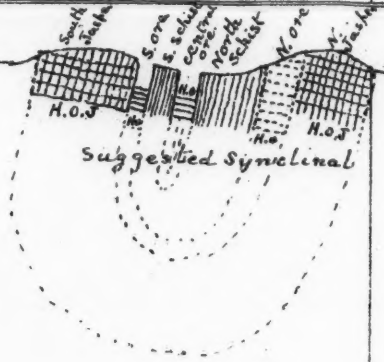
Co.



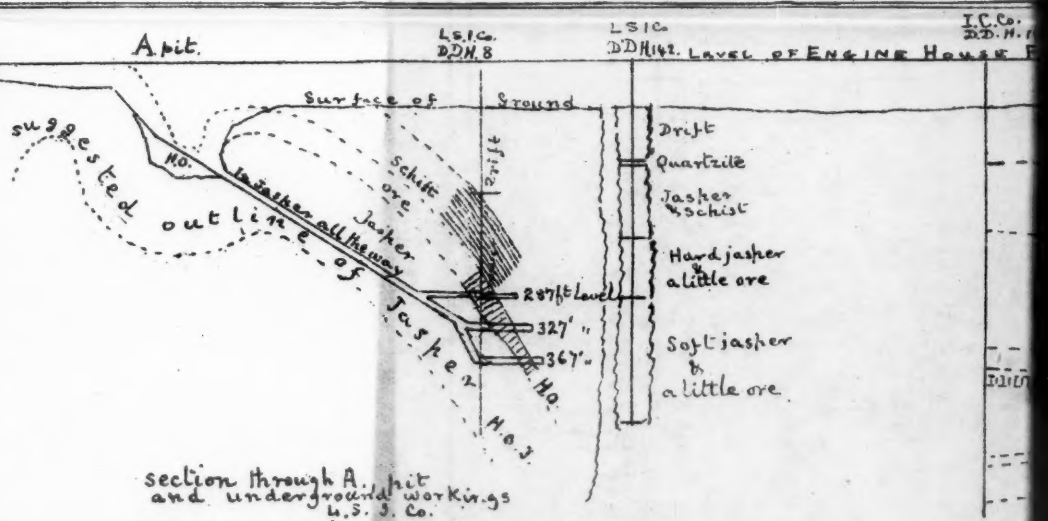
Section on line A. B. on meridian
D.D. Holes projected on supposed line of strike N.74° W.



to meridian



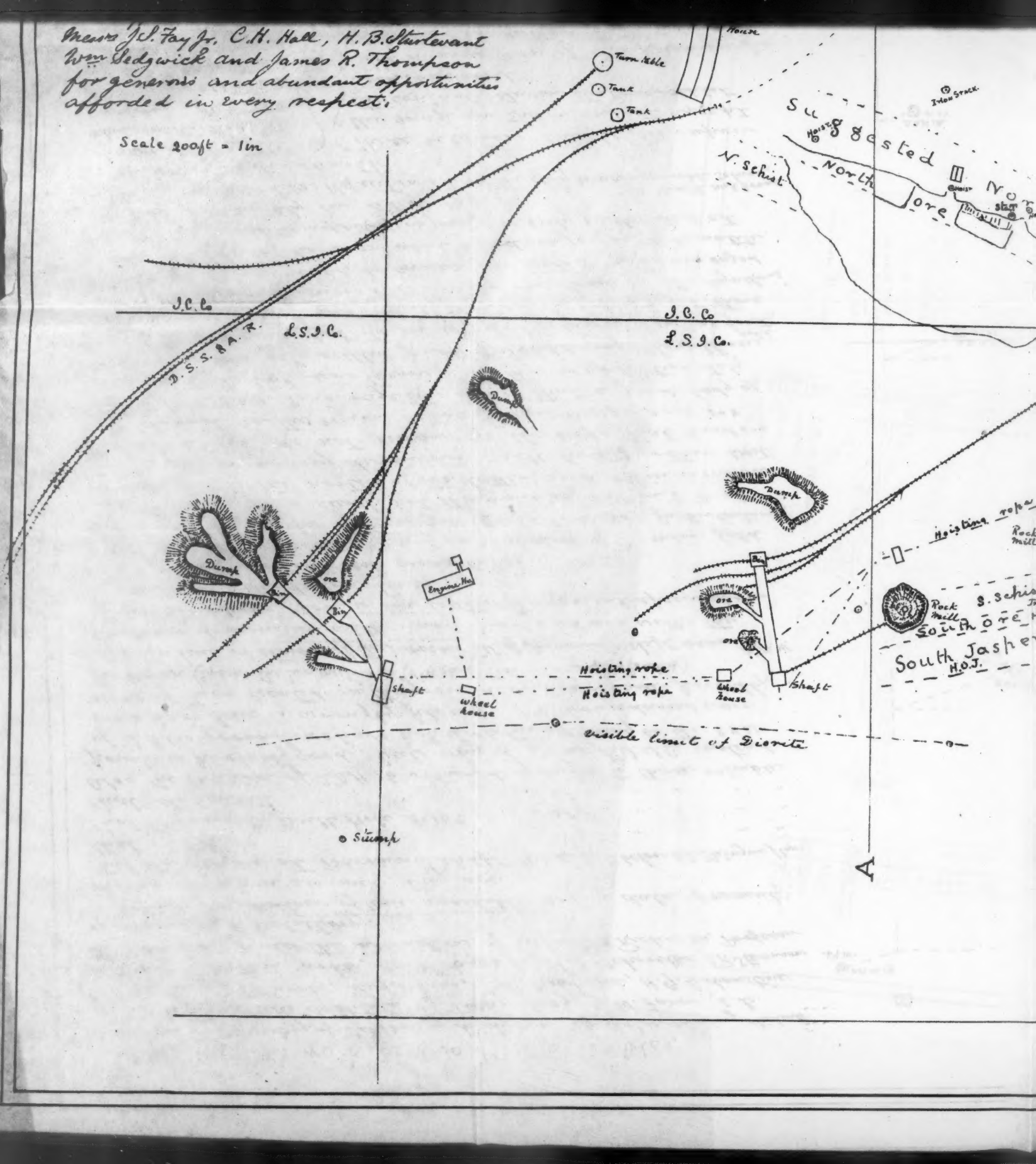
Section marked E.F.
across Jasher hills
Projected to meridian



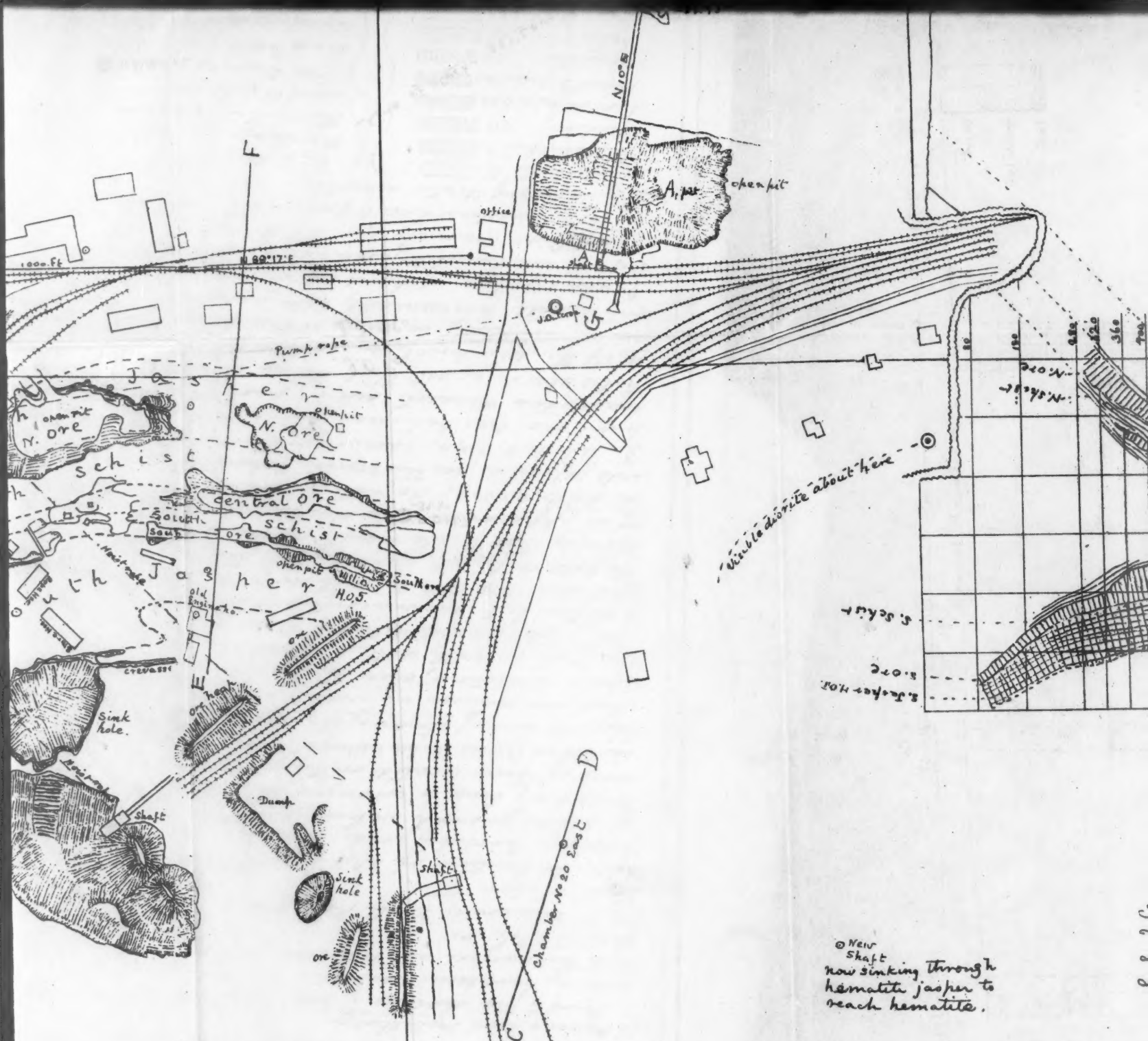
section through A. pit
and underground workings
L.S.I. Co.
On line G H projected to meridian

Messrs J.S. Fay Jr. C.H. Hall, H.B. Sturtevant
Wm Sedgwick and James R. Thompson
for generous and abundant opportunities
afforded in every respect.

Scale 200ft = 1in

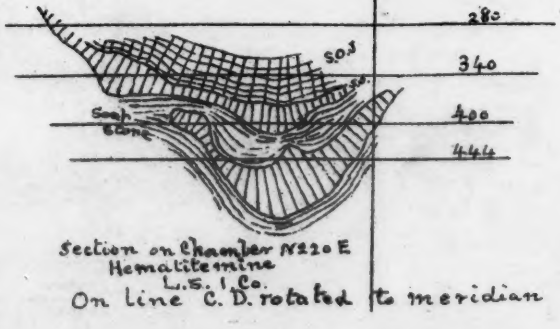


U.S.G.
Base line 1000 Ft
Ore. Space
Shaft
No 3 Shaft
Engine House
Rock mill
Hard Ore Great pit
House Chimney
Sink hole
Hematite Great pit
Dump
Old Engine Ho.
Ore Heap
Crevasse
Level
Jasper
schist
N. Ore
central Ore
South Ore
open pit
S

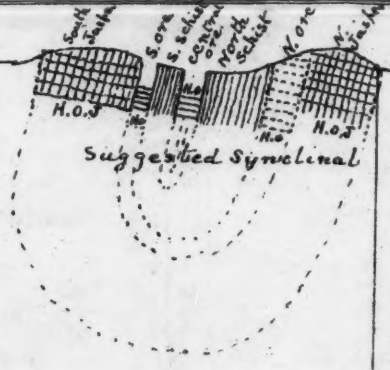

N 10° E
A, pit
open pit
office
1000 Ft
N 89° 17' E
Pump rope
Jasper
open pit
N. ore
schist
central ore
South ore
schist
Main rope
South Jasper
H.O.5.
old Engine ho.
ore
crevasse
Sink hole.
ore heap
Dump
Shaft
Sink hole
ore
Shaft
Chamber No 20 East
C
D
visible diorite about here
S. Jasper H.O.5
S. ore
S. schist
N. ore
N. schist
New Shaft now sinking through hematite jasper to reach hematite.

L. S. I. Co
Cleveland Co.

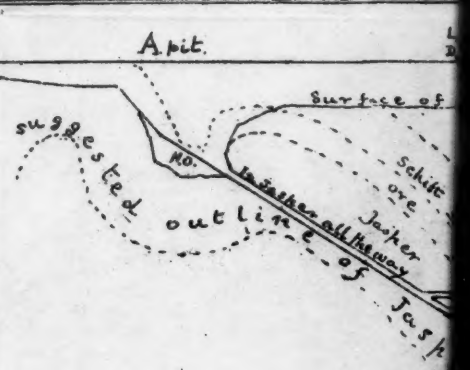
Section
D.D. Holes proje



Section on Chamber N220 E
Hematite mine
L.S.I. Co.
On line C. D. rotated to meridian



Section marked E.F.
across Jasper hills
Projected to meridian



section through A. pit
and underground wor
L.S.I. Co.
On line G H projecte

THE TECHNOLOGY QUARTERLY.

THE TECHNOLOGY QUARTERLY is a scientific journal representative of the work carried on at the Massachusetts Institute of Technology. It is intended that each number shall contain articles of permanent value in the various departments of scientific investigation — in Mathematics, Engineering, Physics, Chemistry, Geology, Biology, Zoölogy, History, Economics, etc.

The subscription price is $2.00 per year (post-paid), payable in advance; single copies, 60 cents.

Address, MASSACHUSETTS INSTITUTE OF TECHNOLOGY,
Boston, Mass.

THE TECH.

Published on alternate Thursdays, during the school year, by the students of the Massachusetts Institute of Technology.

Subscription, $2.00 per year in advance. Single Copies 15 cts. each.

TECHNOLOGY ARCHITECTURAL REVIEW.

PUBLISHED FROM

THE DEPARTMENT OF ARCHITECTURE,

MASSACHUSETTS INSTITUTE OF TECHNOLOGY.

Eight numbers constitute a yearly volume.

Subscription, $3.00 per volume.

HENRY D. BATES,
THOMAS R. KIMBALL,
IRVING T. GUILD,
} *Publishers.*

863 AND 865 BROAD STREET.
NEWARK.

112 AND 114 LAKE STREET.
CHICAGO.

RICHARDS & CO., LIMITED,

Assayers' and Chemists' Supplies,

41 BARCLAY ST., NEW YORK.

SAMUEL CABOT,

MANUFACTURING CHEMIST.

COAL TAR PRODUCTS,

CREOSOTE STAINS, MORTAR COLORS, LAMPBLACK, AND OTHER SPECIALTIES.

OFFICE, 70 KILBY STREET,

FACTORIES:
CHELSEA, MASS., BUFFALO, PA.

BOSTON, MASS.

CROSBY STEAM GAGE AND VALVE CO.,

VALVE.

MANUFACTURERS OF THE

Crosby Improved Steam Gage,

CROSBY POP SAFETY-VALVE,
CROSBY WATER-RELIEF VALVE,
CROSBY STEAM-ENGINE INDICATOR.

Also, Bourdon Pressure and Vacuum Gages, Hydraulic, Compound, Combination, Test, Ammonia, and all other Gages. Revolution Counters, Marine Clocks, Test-Pumps, etc., etc. **VICTORY STEAM-CYLINDER LUBRICATOR,** and **SINGLE-BELL CHIME WHISTLE.**

CHIME.

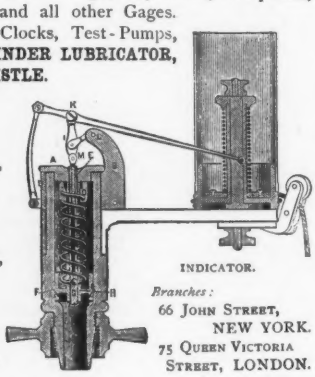
IMPORTERS OF
AMSLER'S POLAR PLANIMETER.

At the PARIS UNIVERSAL EXPOSITION of 1889, the Highest Award, a

GOLD MEDAL,

Was given to this Company for
Indicators, Safety-Valves, Steam Gages, and Lubricators.

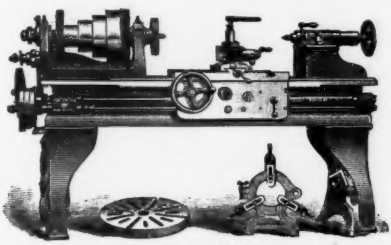
OFFICE AND SALESROOM,
(To which address all letters,)
93 OLIVER STREET, BOSTON, MASS.



INDICATOR.

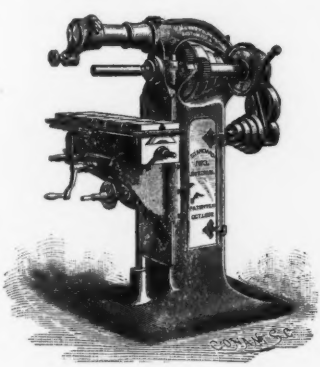
Branches:
66 JOHN STREET,
NEW YORK.
75 QUEEN VICTORIA
STREET, LONDON.

HILL, CLARKE, & CO.,



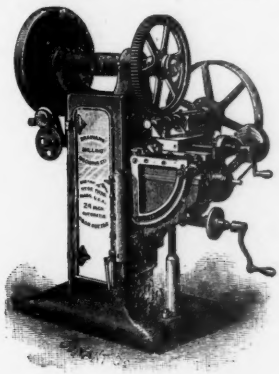
FLATHER ENGINE LATHE.

IRON-WORKING MACHINE TOOLS,



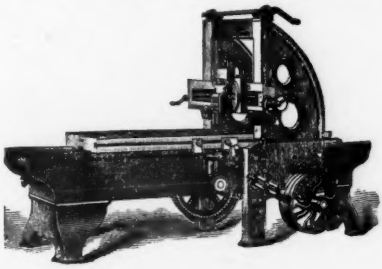
BRAINARD GEAR CUTTER

AND



BRAINARD MILLING MACHINE.

MACHINE-SHOP SUPPLIES,

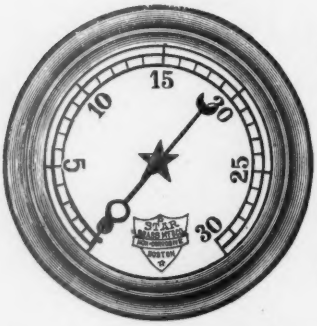


FLATHER IRON PLANER.

156 OLIVER STREET, BOSTON, MASS

C. W. SHERBURNE, Pres't. CHARLES WINTHER, Sup't.

STAR BRASS MANUFACTURING CO.,



MANUFACTURERS OF

STEAM, WATER, AND VACUUM

GAGES,

With Non-Corrosive and Non-Magnetic Movements.

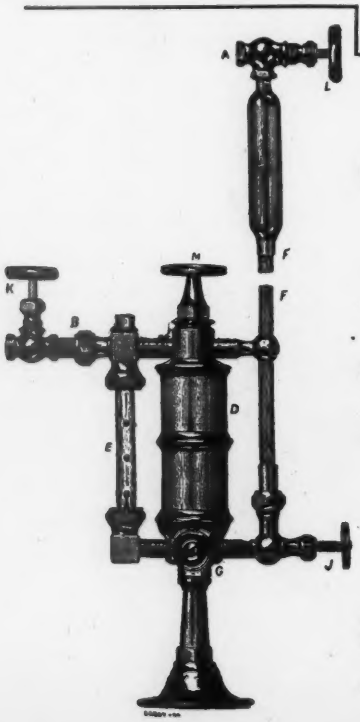
REVOLUTION COUNTERS,
MARINE AND LOCOMOTIVE CLOCKS,
SIGHT FEED LUBRICATORS AND OIL CUPS.

RAILWAY AND STEAMSHIP LAMPS,

AND CAR TRIMMINGS OF EVERY DESCRIPTION.

OFFICE: 53 OLIVER ST. **BOSTON, MASS.** FACTORY: 31-37 LANCASTER ST.

Catalogue and prices furnished on application.



THE SEIBERT CYLINDER OIL CUP COMPANY,

53 OLIVER ST., BOSTON, MASS., U. S. A.,

MANUFACTURERS OF

PATENT AUTOMATIC SIGHT-FEED **LUBRICATORS.**

Also DOUBLE-SIGHT LUBRICATORS FOR COMPOUND ENGINES,

Under Gates, Seibert, and other Patents.

By their use oil is seen passing in drops to cylinders and valves, which are perfectly lubricated, making a large gain in power and saving in coal.

N. B. Infringers will be prosecuted.

☞ Send for Catalogue and price.